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INTERIM DEVELOPMENT REPORT

FOR

W.O.800-36147 - MAGNETIC PARTS, GASEOUS OR LIQUID FILLING OF.

THIS REPORT COVERS THE PERIOD. 1 DEC 1953 . . TO. 28 FEB 1954.

RAYTHEON MFG. CO.
WALTHAM (54) MASS.

NAVY DEPARTMENT BUREAU OF SHIPS ELECTRONICS DIVISIONS

CONTRACT NO. NObsr-63239 - INDEX NO. NE 110915 DATE 24 FEBRUARY 1953

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ABSTRACT

THIS REPORT COVERS WORK PERFORMED IN CONNECTION WITH PHASE II AS DEFINED IN PART I – PURPOSE.

THE END OF THE PERIOD COVERED APPROXIMATELY COINCIDES WITH THE COMPLETION OF THIS PHASE, MAKING THIS REPORT IN EFFECT A COMPLETION REPORT OF PHASE II.

PART I, SECTION 3 – DETAIL FACTUAL DATA HAS BEEN SUB-DIVIDED INTO ELEVEN SEPARATE INVESTIGATIONS, EACH COVERING A SPECIFIC CHARACTERISTIC OF THE MATERIALS FOR WHICH DATA WAS REQUIRED IN ORDER TO ACCOMPLISH PHASE III.

THE VARIOUS INVESTIGATIONS ARE LISTED IN PART I, SECTION 3, (PAGE 6 OF THIS REPORT). THE METHODS AND RESULTS OF THESE INVESTIGATIONS ARE DESCRIBED AND SHOWN IN SUBSEQUENT PAGES IN THAT SECTION.

PHOTOGRAPHS OF THE EQUIPMENT USED ARE INCLUDED AS APPENDIX "B".

[redacted]

PART I

SECTION I

PURPOSE

THE AIMS AND PURPOSES OF THIS WORK ARE AS FOLLOWS:

PHASE I. TO COLLECT AND ANALYZE EXISTING INFORMATION REGARDING THE PROPERTIES OF FLUOROCARBON GASES AND/OR LIQUIDS AND/OR OTHER RECENTLY DEVELOPED APPLICABLE GASES AND OTHER INORGANIC MATERIALS, PARTICULARLY AS TO THEIR USAGE IN MAGNETIC PARTS AT ELEVATED TEMPERATURES IN PRESSURIZED CONTAINERS.

PHASE II. TO INVESTIGATE AND TEST THE GASES AND/OR LIQUIDS AND OTHER MATERIALS APPEARING TO OFFER THE GREATEST PROMISE AS DETERMINED BY EVALUATION OF THE DATA OBTAINED IN PHASE I, INCLUDING THEIR COMPATIBILITY WITH ONE ANOTHER AND WITH OTHER MATERIALS USED IN MANUFACTURE OF MAGNETIC PARTS.

PHASE III. DESIGN, CONSTRUCT AND SUBMIT TO BUREAU OF SHIPS SIX SAMPLES OF EACH OF FIVE TYPES OF MAGNETIC PARTS, USING THE MATERIALS SELECTED AS RESULT OF PHASES I & II.

PHASE IV. (TO BE UNDERTAKEN ONLY AFTER APPROVAL BY BUREAU OF SHIPS OF THE WORK OF PHASE I, II, & III) PRODUCTION, USING PRODUCTION TECHNIQUES OF TWELVE UNITS OF EACH OF THE FINAL DESIGN.

[redacted]

GENERAL FACTUAL DATA

1. IDENTIFICATION OF TECHNICIANS

   SEE APPENDIX – TABLE I

2. PATENTS

   a. ISSUED – NO. 2,447,489 – "LEAD IN BUSHING"
      R. U. CLARK – ASSIGNED TO RAYTHEON MFG. CO.

   b. PENDING – DISCLOSURE NO. 1646
      "DIRECTLY COOLED ELECTRO MAGNETIC COMPONENTS"
      ROBERT G. HAAGENS & LEONARD KATZ

   c. BEING PREPARED –
      "TEFLON MOULDED COILS FOR TRANSFORMERS"
      W. L. ROOT, JR., & EDW. McLAUGHLIN

      "MINIMIZING EXCESSIVE CAPACITANCE IN PULSE TRANSFORMERS"
      STEPHEN HANNON & GEO. W. HALDER

3. REFERENCES (BIBLIOGRAPHY)

   a. "GASEOUS INSULATION FOR HIGH VOLTAGE TRANSFORMERS" CAMILLI, GORDON & PLUMP– A.I.E.E. TECHNICAL PAPER 52-78 WINTER GENERAL MEETING, JANUARY 1952.

   b. "GASEOUS INSULATION FOR HIGH VOLTAGE APPARATUS" CAMILLI & CHAPMAN– A.I.E.E. TRANSACTIONS VOL. 66, 1947

   c. "EFFECT OF HIGH VOLTAGE ELECTRICAL DISCHARGES ON SULFUR HEXAFLUORIDE" SCHUMB, TRUMP & PRIEST. INDUSTRIAL & ENGINEERING CHEMISTRY VOL. 41, JULY 1949

   d. "THE DIELECTRIC STRENGTH OF GASEOUS FLUOROCARBONS" WILSON, SIMMONS & BRICE.

   e. "FLUOROCARBONS" – A BROCHURE PUBLISHED BY MINNESOTA MINING AND MANUFACTURING COMPANY.

   f. "ELECTRICAL PROPERTIES – INERT LIQUIDS" A BROCHURE PUBLISHED BY MINNESOTA MINING AND MANUFACTURING COMPANY.

   g. "SOME FLUORINATED LIQUID DIELECTRICS" N.M. BASHARA A.I.E.E. TECHNICAL PAPER 53-135 WINTER GENERAL MEETING JANUARY 1953.

   h. "SOME FLUOROCHEMICALS FOR ELECTRICAL APPLICATIONS" N.M. BASHARA – PROCEEDINGS SYMPOSIUM ON PROGRESS IN QUALITY ELECTRONIC COMPONENTS. (WASHINGTON, D.C.) MAY 1952.

   i. "SULFER HEXAFLUORIDE" – A BROCHURE PUBLISHED BY GENERAL CHEMICAL DIV., ALLIED CHEMICAL AND DYE CORP.

   j. "PROPERTIES OF KEL-F OILS, GREASES AND WAXES" KEL-F TECHNICAL BULLETIN #5-1-52. THE M. W. KELLOGG CO.

   k. "LEAK DETECTOR, TYPE H" A BULLETIN OF GENERAL ELECTRIC CO.

[redacted]

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l. "ELEGAS (SF6) GASEOUS ELECTRICAL INSULATION" B.M. HOCHBURG ELEKTRICHESTVO (1947) NO. 3

m. "RESEARCH PROGRESS IN DIELECTRICS - 1952" ALEX JAVITZ-ELECTRICAL MANUFACTURING FOR DEC. 1952.

n. "TEMPERATURE PREDICTION IN ELECTRONIC DESIGN" P. F. SELGRIM AND B. K. HAWKES. ELECTRICAL MANUFACTURING FOR OCT. 1952.

o. "FLUOROCARBON RESINS APPRAISED" ALEX. JAVITZ-ELECTRICAL MANUFACTURING FOR AUG. & SEPT. 1950.

p. "HIGH OPERATING TEMPERATURE TRANSFORMERS" FINAL REPORT-CONTRACT W-33-038-ac-13939. AIR MATERIAL COMMAND, WRIGHT-PATTERSON AIR FORCE BASE.

q. "DESIGN & DEVELOPMENT OF MINIATURE HERMETICALLY SEALED POWER TRANSFORMERS" FINAL REPORT ARF PROJECT NO. 90-686E CONTRACT W-36-039-sc-38221

r. "FLUOROLUBES" (BOOKLET #30) HOOKER ELECTROCHEMICAL CO.

s. "PERFLUOROCARBONS" A BROCHURE PUBLISHED BY E. I. duPONT de NEMOURS CO.

t. "SULFUR HEXAFLUORIDE - PROPERTIES AND METHOD OF HANDLING" PENNSYLVANIA SALT MFG. CO.

u. "HALOCARBON OILS, WAXES & GREASES" HALOCARBON PRODUCTS CORP.

v. "ELECTRICAL PROPERTIES OF CERTAIN FLUORINATED HYDROCARBONS" NAVY RESEARCH LAB. REPORT #3836

w. "COOLING OF AIRBORNE ELECTRONIC EQUIPMENT, VOL. I & VOL. 2. SECOND CONFERENCE AT OHIO STATE UNIVERSITY, JUNE 23 & 24, 1953.

x. "PREPARATION, PROPERTIES & TECHNOLOGY OF FLUORINE AND ORGANIC FLUORIDE DERIVATIVES" BY SLESSER & SCHRAM McGRAW-HILL

y. "LIQUID DIELECTRICS" GEMANT JOHN WILEY

[redacted]

SECTION 3

DETAIL FACTUAL DATA

INTRODUCTION

The data presented in the following pages is divided into twelve separate topics. Graphs tables and pictures are used to illustrate and amplify the written material.

This quarterly report period fortunately coincides with the conclusion of Phase II activity in the project. It is thus possible to present completed work in all of the topics covered whereas some previous quarterly reports were, in effect, progress reports.

Two main objectives in Phase II are:

A. The selection of the most generally suitable fluorochemical liquids and gases.

B. The obtaining of data establishing the particular design parameters introduced by the use of fluorochemical dielectrics with an eye to both advantages and limitations.

The work undertaken and reported below was in fullfilment of the above objectives. The topics are listed as follows:

A. Power Factor and Dielectric Constant Data Accumulated.

B. Results of Thermal Stability on Fluorochemical Liquids.

C. Corona Level and Breakdown Strength of Gaseous Fluorochemicals.

D. Purification of Fluorochemical Liquids.

E. Compatibility Testing of Commonly Used High Temperature Transformer Construction Materials with Fluorochemical Liquids.

F. Selection of Most Suitable Liquid for Power Transformers on the Basis of Pressure Characteristics.

G. Selection of Proper Liquid for a Given Set of Operating Conditions.

H. Use of Sulphur Hexafluoride at Reduced Pressures in the Expansion Space of Fluorochemical Filled Transformers.

I. Thermal Runs with Resistor Heat Source.

J. Physical and Electrical Characteristics of Selected Fluorochemicals.

K. Plasticized Teflon as a Terminal Material.

Graphs and tables will be shown in the text, photographs in appendix B.

Following the detailed presentation of the twelve topics, a summary and conclusion will be presented based on the Phase II objectives stated above.

PART I

Section 3 (Cont'd)

DETAIL FACTUAL DATA

INVESTIGATION A

DIELECTRIC CONSTANT AND POWER FACTOR MEASUREMENTS ON FLUORO-CHEMICAL LIQUIDS AT ROOM TEMPERATURE.

Subject measurements were taken on a General Radio 716-C Schering Bridge and associated equipment (oscillator, amplifier, indicator etc.) Readings were taken at frequencies of 50~, 100~, 400~, 1 KC, 10 KC and 100 KC.

In order to minimize inaccuracies inherent in the direct reading method all measurements were taken using the substitution method. The step-by-step procedure was as follows:

1. The bridge was set up as described on page four of the operating instructions. A variable air capacitor (50 $\mu\mu f$ - 1000 $\mu\mu f$) was used as an external balancing capacitor.

2. The bridge was energized and balanced with the unknown leads removed. In this original balance, the balancing capacity was set at such a value as to make a balance occur with approximately 1000 $\mu\mu f$ on the internal bridge capacitor. This bridge capacitor reading was recorded as Co.

3. Short leads were added to the bridge. The low lead was connected to one set of plates of a Cardwell air-capacitor. The high lead was allowed to rest in the approximate position of use, but no connection was made to the other set of air capacitor plates. The bridge was rebalanced by adjustment of the internal bridge capacitor and dissipation dial. This bridge capacitor reading was denoted as C_B. Then $C_O - C_B$ equals lead capacity.

4. The high lead (ungrounded) was then connected to the air capacitor plates and the bridge rebalanced. The bridge capacity was denoted as C_F. Then $C_B - C_L - C_F$ equals C_A, where C_A equals capacity of air capacitor. The bridge dissipation dial reading was recorded as D_B.

5. Step four was repeated with sample material as dielectric. C_x was obtained. Dissipation dial reading was recorded as D_f.

6. K equals $\frac{C_x}{C_a}$

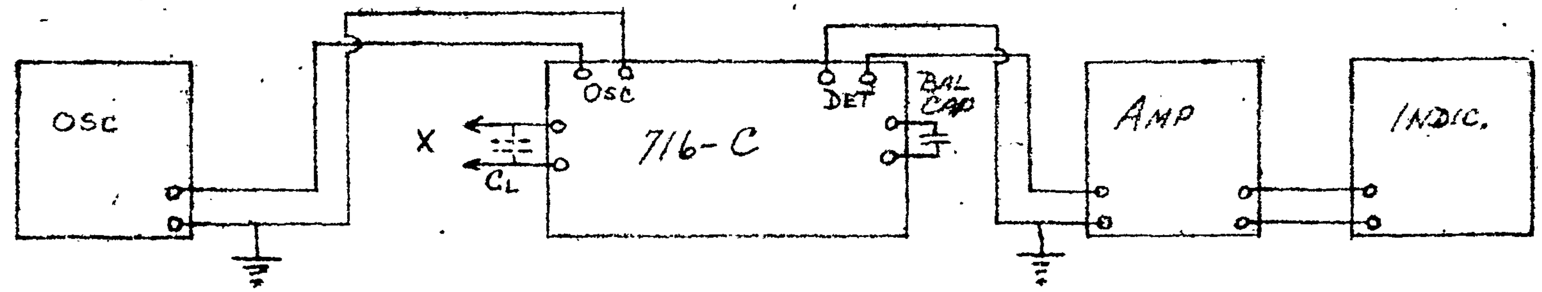
7. Dx equals $\left(\frac{f}{f_o}\right) \frac{C_o}{C_x} \left(D_f - D_B\right)^*$

* $\frac{f}{f_o}$ is a multiplier factor where f equals test frequency and f_o equals bridge multiplier setting.

7. A block diagram of the test circuit is shown on FDP-49 (p 9)

8. The tabulated results are shown on FDP-1 (p 10)

9. The equipment used is illustrated in FDP-10 (appendix B)



SAMPLE TABULATION

$f = 1Kc$ $f_0 = 1Kc$ $\frac{f}{f_0} = 1$ t: room temperature.

MATERIAL	$C_o - C_B = C_L$	$C_B - C_L - C_F = C_A$	$C_B - C_L - C_{FX} = C_X$	$\frac{C_X}{C_A} = K$	$\frac{C_O}{C_X}(D_F - D_B) = D_X$
F1					

CIRCUIT AND TABULATION FOR DIELECTRIC CONSTANT AND POWER FACTOR DETERMINATIONS.

12/3/53 RPM FDP 49

DIELECTRIC CHARACTERISTICS OF FLUOROCHEMICALS
(AT ROOM TEMPERATURE)

MATERIAL		DIELECTRIC CONSTANT						POWER FACTOR %						LOSS FACTOR			INS. R MEG
	TEMP	50~	100~	400~	1Kc	10Kc	100Kc	50~	100~	400~	1Kc	10Kc	100Kc	50~	1Kc	100Kc	DC
KEL-F-3	27°C	2.76	2.74	2.76	2.75	2.76	2.76	.0016	.0018	.0013	.0029	.0025	.008	.0045	.008	.022	200K
O-73	27°C	1.8	1.8	1.8	1.8	1.8	1.8	.0012	.0024	.0016	.0048	.0045	.0048	.0043	.0086	.0086	500K
FLUROLUBE S	27°C	2.8	2.8	2.8	2.8	2.8	2.8	.0008	.0002	.0032	.0048	.002	.0024	.0027	.013	.0067	200K
KEL-F-B	25°C	2.51	2.51	2.51	2.51	2.51	2.51	.01	.022	.031	.025	.007	.005	.023	.059	.012	50K
KEL-F-C	26°C	2.66	2.66	2.66	2.66	2.64	2.64	.0025	.0017	.004	.0034	.0017	.0017	.007	.009	.005	200K
O-75	28°C	1.84	1.84	1.84	1.84	1.84	1.84	.064	.016	.019	.0098	.0098	.029	.118	.018	.053	200K
HOOKER DICHLOROPER-FLUOROBUTANE	26°C	2.3	2.3	2.3	2.3	2.3	2.3	.0064	.0077	.019	.015	.018	.021	.015	.035	.048	200K
KEL-F-10	25°C	2.88	2.86	2.88	2.88	2.88	2.88	.0016	.004	.0042	.0032	.0046	.04	.0046	.0092	.115	125K
N-43	27°C	1.9	1.9	1.9	1.9	1.9	1.9	.0013	.0025	.004	.0095	.005	.005	.0025	.0180	.0095	∞

COMPLETED 2/1/54
A. DIJULIO
L. MC ANDREW

* MULTIPLY LOSS FACTOR BY 10^{-2} TO OBTAIN DECIMAL EXPRESSION

FDP-1

PART I
SECTION 3 (Cont'd)

DETAIL FACTUAL DATA (Cont'd)

INVESTIGATION B

RESULTS OF THERMAL STABILITY TESTS ON FLUOROCHEMICAL LIQUIDS

METHOD OF TEST

All samples were purified with fuller's earth and tested for insulation resistance in the standard 100 mmf. cell.

Low volatility materials, boiling at 230° C. and higher, were heated in glass stoppered bottles in a constant temperature oil bath, one week at 121°C and one month at 150° C.

The more volatile liquids, b.p. up to 205° C, were sealed in Pyrex bomb tubes, encased in copper cylinders, and heated one month in the oven at 117°C.

Results are tabulated on FDP-51 (P12).

FDP-15 Illustrates Equipment used for non-volatile liquids (appendix B.)

FDP-16 Illustrates equipment used for volatile liquids (appendix B.)

RESULTS OF THERMAL STABILITY TEST ON FLUOROCARBON LIQUIDS

Liquid	B. P. deg. C.	Ins. Res. (megs.) after Purifying	Ins. Res. (megs.) After Heat Test	Color & Odor after Heat Test
Fluorolube S		200,000	60,000	Straw Color Dark ppt. Sour Odor
Kel F-10	330	110,000	200,000	Nearly White Good Odor
Halocarbon 11-14	240	120,000	7,000	Medium Straw Much Dark ppt. Odor like HCl
Fluorolube FS	235	60,000	40,000	Almost White Slight Odor
Kel F-3	230	200,000	60,000	Light Straw Odor Good
Kel F-C	205	90,000	40,000	Water White
N-43	177	500,000	500,000	" "
FCX-329	140 - 215	150,000	160,000	" "
Kel F-B	135	50,000	7,000	" "
0-75	102	500,000	50,000	" "
FCX-327	102	500,000	120,000	" "
FCX-326	76	500,000	Not Tested	
Dichloroctofluorbutane	65	200,000	" "	
0-73	56	500,000	" "	

COMMENTS:

N-43 is the most stable of all compounds tested.

Although FCX-327 and 329 showed an apparent stability in sealed tubes better than O-75, the increased cost does not appear justified and the latter is still recommended for phase III work. We now have an improved grade of O-75 on which thermal tests will be continued.

Kel F-10 is the most stable of the chlorofluoro materials. However, no outstanding cooling power may be expected of this liquid, since it is of the non-volatile type, resembling silicone in viscosity.

PART I

Section 3 (Cont'd)

Investigation C

Corona Level and Breakdown Strength of Gaseous Fluorochemicals.

The following is a resume of the findings of the fluorochemical Project-Corona Assignment.

Corona and H. V. Breakdown Tests have been made of the following gases:

1. Air	
2. Nitrogen	-N_2
3. Sulphur Hexafluoride	-SF_6
4. Dichlorodifluoromethane	-$C F_2 Cl_2$ Genetron 12
5. Octofluoropropane	-$C_3 F_8$

The test circuit is diagrammed in FDP7(p. 15. The equipment used is illustrated in FDP-9 (appendix B)

The resultant curves FDP-8 which follows (p-16) shows that all three fluorinated gases that we tested behave better than nitrogen as far as corona or breakdown is concerned, while Sulphur Hexafluoride is superior to the other gases.

It was proven that when the gap is relatively small, corona nearly coincides with breakdown, but if a sufficiently wide gap is used, the breakdown is appreciably higher than corona.

With our existing corona Tester the maximum reliable corona free supply voltage is 10 KV RMS which limits the electrode spacing to about .050". While testing fluorinated gases at high pressures, under this condition, breakdown and corona occur almost simultaneously at the medium and low pressures.

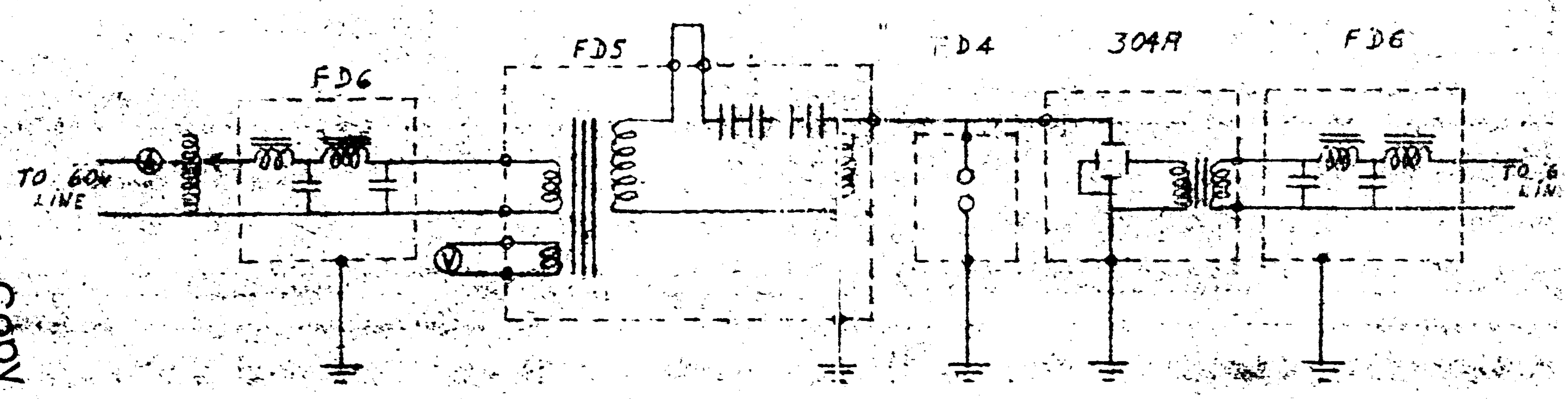
The pressurized spark gap chamber breaks down externally slightly above 40 KV RMS, which limits the electrode spacing to about .100". While testing fluorinated gases at high pressures, with this gap, corona occurs well above the 10 KV limitation.

The report "DIELECTRIC STRENGTH" of Gaseous Fluorocarbons" by Wilson-Simons-Brice, point out that gaseous Fluorocarbons have a breakdown potential equal or greater than fluoro-organic gases and prove it by graphs.

Their Dry Nitrogen curve follows the same curve as ours, but their SF_6 curve shows breakdown at slightly lower voltages.

The report "Gaseous Insulation for H.V. Transformers" by Carmilli-Gordon-Plump and also the report "Gaseous Insulation for H.V. Apparatus" by Camilli-Chapman display curves of several gases with gaps varying from 1/2" to 3", which after proper analysis and approximations, compare favorably with our curves.

"CORONA TEST CIRCUIT"



FD4 - Pressurized Spark Gap Chamber, 1 Quart Capacity
FD5 - 10KV Corona Tester, with Hi Pass Filter 70 KC cut-off
FD6 - Line Filter, Low Pass Filter 1KC cut-off
304A - Dumont 5" Scope
A - AC Ammeter 0-5A
V - AC Voltmeter 0-30V.

The corona voltage as stated in these reports, is the minimum operating voltage impressed on the Chamber FD4 in order to produce ionization shown as minutes pikes super imposed in the basic 60 cycles waveform as seen in a scope adjusted to a sensitivity of 0.1 Volt per inch peak to peak voltage; the given corona voltages are the average of three test readings.

FDP-7
Jan-57
K. Tho...

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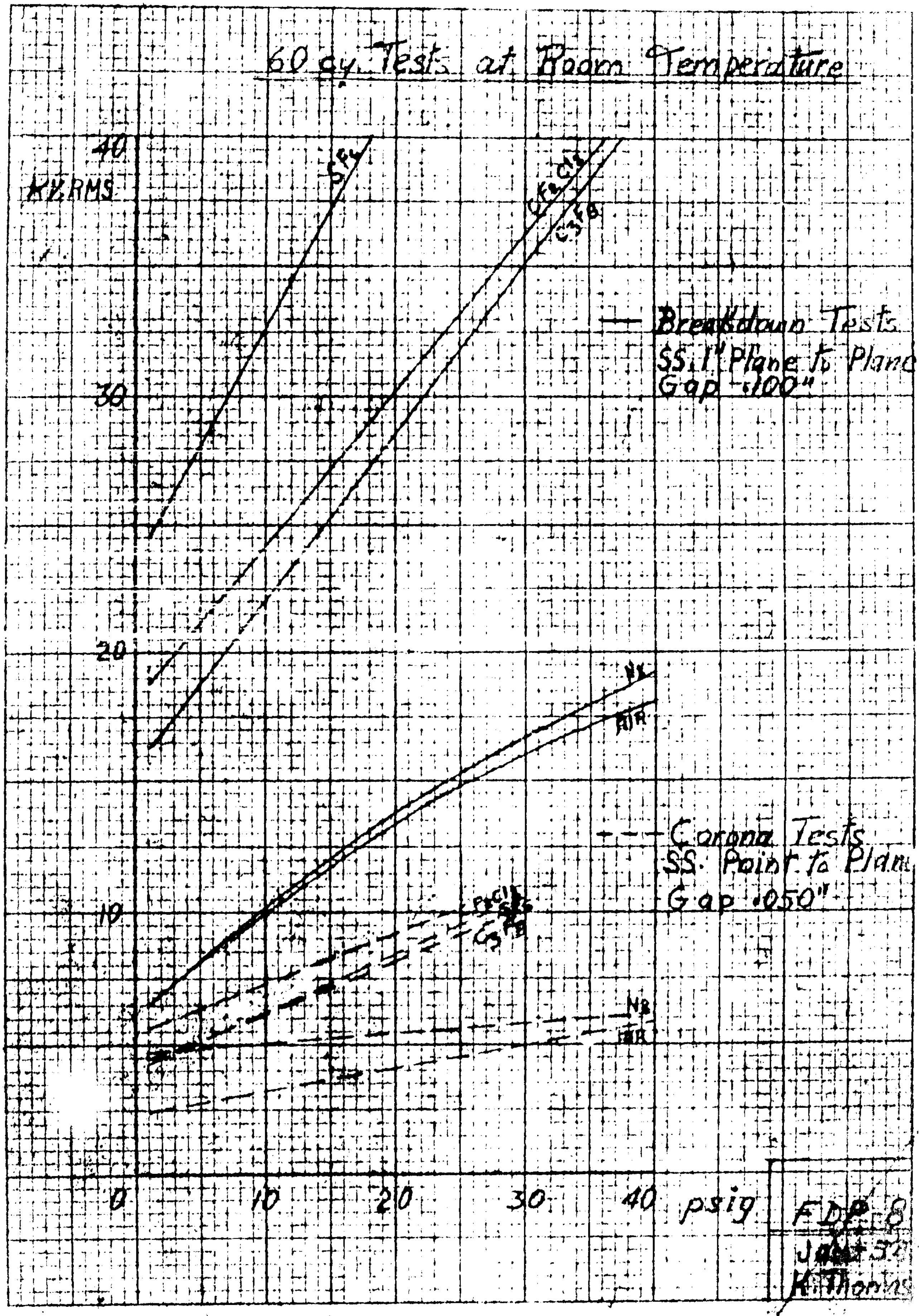

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INVESTIGATION - D

PURIFICATION OF FLUOROCHEMICAL LIQUIDS

Fourteen samples of fluorochemical liquids have been purified and tested for dielectric characteristics.

The method of purifying was as follows: The sample was shaken four minutes with 5% caustic soda solution at 50-60 deg. F., and allowed to settle in a separatory funnel. The fluorochemical liquid was drawn off and passed through 10 inches of fuller's earth, (16-30 mesh, pre-dried at 300 deg. F.) in a chromatographic column of pyrex glass, 3/4 in. in diameter, at a temperature of 80-90 deg. c., except for the low boiling liquids, which were run through just below the boiling point. Vacuum was used where necessary for the more viscous materials. The fuller's earth treatment was repeated until maximum resistance readings were obtained. Ordinarily three passes through the column were sufficient. The fuller's earth and all accessory glassware was dried immediately before use. This apparatus is illustrated in FDP-14 - (appendix B.)

Insulation resistance and power factor were measured in a cell which consisted of a Cardwell type JD-100-os fixed air condenser, 100 mmf. nominal capacity (110 mmf. actual) with plates spaced .125 in. A cell of this type fits snugly in a 400 cc. Griffin beaker. The General Radio 544B megohm bridge was used for insulation resistance measurement, and the Leeds and Northrup Schering bridge for power factor in conjunction with a 1 Kc oscillator, amplifier, and visual null detector. Dielectric constants were also measured, but showed no significant change on purification. This equipment is illustrated in FDP-11 (appendix B.)

Results are tabulated on FDP-52 - (P-18.)

DIELECTRIC CHARACTERISTICS OF FLUOROCHEMICAL LIQUIDS BEFORE AND AFTER PURIFICATION

(Conventional transformer oils are included for comparison)

Liquid	B.P. deg. C	Before Purifying: % P F 1000 ~	Before Purifying: Ins. Res. megs 28°C	After Purifying: % P F 1000 ~	After Purifying: Ins. Res. megs 28°C	Spec. Res. ohms/cm³ (IR x 1.25 x 1(
Conventional Oils:						
Transil	>250	.014	60,000 - 200,000	.01	500,000	6.3×10^{14}
Silicone 100 cp.	High	.01	>500,000			6.3×10^{14}
Perfluoro Compounds:						
N-43	177	.015	60,000	.015	500,000	6.3×10^{14}
0-75	102	.024	200,000 (when rec'd) 500,000 (aft. 2mos.)		--	6.3×10^{14}
0-73	56	.023	17,000	.015	500,000	6.3×10^{14}
FCX 326	76	.08	75,000	.00	1,000,000	12.5×10^{14}
FCX 327	102	.066	5,800	.04	70,000 225,000 (aft. 1 mo.) 500,000 (aft. NaOH treat.)	$.9 \times 10^{14}$ 2.8×10^{14} 6.3×10^{14}
FCX 329	140-215	.087	80,000	.015	150,000	1.9×10^{14}
Chlorofluoro Compounds:						
Kel F-B	135	.10	2,300	.03	50,000	$.6 \times 10^{14}$
Kel F-C	205	.07	11,000	.04	90,000	1.1×10^{14}
Kel F-3	230	.07	50,000	.01	200,000	2.5×10^{14}
Kel F-10	330	.07	6,200	.01	110,000	1.4×10^{14}
Fluorolube S	High	.005	20,000	.01	200,000	2.5×10^{14}
Fluorolube FS	235	.134	970		60,000	$.8 \times 10^{14}$
Dichlorocto-fluorbutane	65	.123	1,400	.015	200,000	2.5×10^{14}
Halocarbon Oil [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.5×10^{14}

Observations made during the course of treatment.

1. Two of the liquids had etched the inside of the glass containers. O-75 caused a slight etching, FCX-329 (perfluorinated kerosene) a severe etching. It is, of course, not known how long the samples had been in the bottles before shipment to us. The etching is believed to be due to traces of free hydrofluoric acid in the samples.

2. Certain of the perfluoro liquids improved dielectrically on standing in glass bottles. O-75 changed from 200,000 megohms to 500,000 in two months. FCX-327 tested 70,000 megs immediately after purifying, and after one month the resistivity had increased to 225,000 megs. A possible explanation is offered in the reaction of the glass container with traces of free hydrofluoric acid present in the liquid, forming an insoluble silicofluoride and effectively removing the free acid.

3. The foregoing phenomena suggest a tentative method of stabilizing the liquids by the inclusion of silicious material (glass, silica, fuller's earth, etc.) within the transformer case. Activated alumina has already been proposed in the literature as a means of removing degradation products resulting from arcing in SF_6- filled circuit beakers and switchgear. The writer has found that fuller's earth exerts a pronounced stabilizing (or, more precisely, continuous purifying) effect on mineral oil kept at elevated temperatures. A report on this subject will be placed in the fluorochemical file.

The use of small quantities of silicone oil is under consideration as a stabilizing agent, since it is known that fluorochemicals attack the silicones.

4. Most of the fluorocarbon liquids produced little or no discoloration when shaken with caustic soda. The exceptions were the DuPont samples FCX-326 and 327 (fluorinated methyl cyclohexanes) and FCX-329 (fluorinated kerosene).

An attempt was made in the case of FCX-327 to remove substances causing discoloration by boiling for a prolonged period (16 hours) with 5% caustic soda solution. At the end of this time, a dark brown alkaline extract was obtained. On removing the fluoro liquid and again shaking with N_aOH, additional colored extract was obtained, but the color was much lighter than that obtained on the original sample as received, indicating that a portion of the discoloring agent had been removed. The sample which had been boiled with N_aOH tested 500,000 megs at 43° after a single pass through 4 inches of fuller's earth.

The maximum resistivity attainable on the same sample before boiling with N_aOH was 70,000 megohms.

The dielectric constant before and after N_aOH treatment was the same. It is concluded, therefore, that the bulk of the material was unchanged in the process. If any major change had occurred, the dielectric constant would have been increased due to the introduction of hydroxyl groups in the molecule by hydrolysis.

In connection with the above, it is interesting to note that the percentage of hydrolyzable fluoride reported by Minnesota Mining for their products is exceedingly small, in the order of .001% or less. The 3M liquids gave no discoloration with caustic soda. Our tests would indicate that the per cent hydrolyzable floride in the DuPont samples is high.

Conclusions

At the present point in the investigation, the expected superiority of the perfluorochemical over the chloroflоro compounds is apparent. The 3M liquids F-43 and O-73 had initially low power factor and their resistivity was easily increased to a high value by fuller's earth treatment. O-75 did not require purification. The FXC liquids had higher power factor as received, but again improvement was accomplished without difficulty. The discoloration on treatment with caustic soda may indicate the presence of reactive impurities which should be removed. It is proposed to take this matter up with DuPont.

Some of the chlorofluoro compounds responded well to fuller's earth treatment, but in general a more prolonged processing was required to achieve maximum results. Rechecks on some samples have shown deterioration on standing at room temperature.

Tests are now under way to determine stability of the purified liquids at elevated temperature. Liquids which prove stable will be further tested in contact with metals commonly used in transformers.

INVESTIGATION E

Compatibility Testing of Commonly Used High Temperature Transformer Construction Materials with Fluorochemical Liquids.

Tests to determine the compatibility of fluorochemical liquids with materials commonly used in the manufacture of high temperature transformers were undertaken as indicated in our previous report. Three cooperating vendors ran compatibility tests with common high temperature transformer construction materials sealed in ampules together with their specific fluorochemicals, and tested these for a considerable period of time at high temperatures. A most complete report was received from Minnesota Mining and Manufacturing Company which indicated, in general the following characteristics.

The volatile perfluoro 3M liquids showed, in general, little or no effect on most transformer materials with the exception of silicone rubber. A corrosive action on high temperature solder is being studied in detail and this work may be expected to show a means of solving this problem. Interim reports on 3M second round compatibility testing with the further purified 3M liquids indicate that the compatibility problem will be considerably mitigated as a result of the extra purification.

The semi-volatile chlorofluoro Kel F-C liquid produced by the M. W. Kellogg Company as used showed a plasticizing effect on teflon. The extent of the noted effects on all materials with Kel F-C exceeded that noticed with the 3-M liquids. No unusual effects were reported on solder. All noted a resultant gain in weight.

The light non-volatile chlorofluoro oil, Fluorolube FS, used in the Hooker Electro Chemical Company tests resulted in milder effects of the same type of changes noted for Kel F-C.

The three classes of common transformer materials subjected to fluorochemical compatibility tests included teflon, silicone products and metals. FDP-13 which follows (P 23) shows a condensation of the Results of Compatibility Tests.

The following are brief statements of materials and resulting action when immersed in fluorochemicals.

TEFLON

The fluorochemical plasticized the teflon. A gain at high temperature and swelling in size is noted. This effect is not damaging to final end use.

Silicone Products

(a) Silicone rubber products are damaged beyond the point of usefulness by a solvent action and degredation of cure.

(b) Silicone varnishes are less effected then silicone rubber. A plasticizing action appears to be the mechanism.

Metals

Attack on exposed copper is noted with the chlorofluoro compounds; the perfluoro compounds show but slight effect. Solder, a troublesome factor in conjunction with 3M liquids is not effected by the others. Attack on iron was noted in one test on chlorofluoro liquids.

Remedial Action with regard to silicone rubber

It is believed that some formulations can be selected to be more resistant than those tested. There is no silicone rubber problem in that teflon can be used instead.

Remedial Action with respect to Silicone Resins

Some formulations can be selected to be more effective in the presence of fluorochemicals than those tested. A longer precure will benefit all silicone resins.

Remedial Action with respect to metals.

Plating of copper could solve this problem. It is believed that the Minnesota Mining study will eventually circumvent the noted effect on high temperature solder.

Compatibility Test Conclusions: The 3M perfluoro liquids present fewer compatibility problems and appear suitable for use with all construction materials, except rubber.

Liquids Tested

TABLE I

Designation	Type	Vendor
N-43	Perfluoro Amine Volatile Liquid	Minnesota Mining
0-75	" Ether " "	" "
KelF-C	Monochloro-trifluoro-ethylene Semi-volatile liquid	M. W. Kellogg
Fluorolube FS	" " " Non-volatile liquid	Hooker Electrochemical

Effects Noted

TABLE II

Type	Material	Remarks
Plasticizing	Teflon - Silicone Varnish	Maintains strength and usefulness.
Solvency	Silicone Rubber	Degeneration of strength and usefulness.
Corrosion	Copper	Extensive corrosion of surface - discoloration of liquid.

Order of Severity of Effects (non Metals)

TABLE III

Liquids	Materials	Max. Degree of Severity	Application
1) Kel F-C	1) Silicone Rubber	60% Wt. Increase	Terminals
2) Fluorolube FS	2) Silicone Resins	18% "	Coatings & Impregnants
3) N-43 and 0-75	3) Teflon	7% "	Terminals & Wire, Insul.

Corrective Methods.

TABLE IV

1) Greater chemical purity of liquids.
2) Silver plating of copper.
3) Selection of silicone rubber formulas.
4) " " " resin ".
5) More extensive pre-cure of silicone resin materials.

PART I

Section 3 (Cont'd)

Investigation F

Selection of Most Suitable Fluorochemical Liquid for Power Transformers on the basis of Pressure Characteristics.

A limiting factor in the use of volatile or semi-volatile fluorinated liquids in transformers is the pressure that will develop within the case under normal and perhaps abnormal operating conditions. For purposes of design, therefore, it is necessary to know what pressures may be expected using any particular liquid, at various ambient temperatures and at various wattages loss per unit surface area of case. On this basis the liquid most suitable for a given application may be selected.

In order to provide this information, pressure tests have been run on three of the liquids which at the present time seem to offer greatest promise from the standpoint of stability and non-corrosive character. The following liquids were tested:

FCX-332	Perfluoromethylcyclohexan	b.p.	76°C
O-75	Perfluorodibutylcycloether	b.p.	102°C
N-43	Perfluorodibutylamine	b.p.	177°C

The tests were carried out as follows. The cylindrical vessel equipped with pressure gauge was approximately half filled with liquid, sealed and placed in the oven until the pressure reached a constant value. The temperature was increased and the unit allowed to attain equilibrium at the higher temperature. Two to three hours were required for each temperature increment of 10°C. Sufficient points were obtained in this manner to plot curves of pressure vs. temperature for the three liquids, as in FDP-2 which follows (P-27). The equipment is illustrated in FDP-17 (appendix B).

The curves obtained are approximately straight lines when plotted on semi-log paper and may be regarded as typical of fluorochemical liquids within the same range of volatility. Other liquids not tested may be expected to exhibit similar pressure - temperature relationships, varying only in the slope of the curve. These curves differ from the true vapor-pressure curve in that they are the resultant of the vapor pressure of the liquid and the gas pressure over the liquid which is influenced by the thermal expansion of the liquid and the temperature of the gas.

The measurements were made at a ratio of vol. gas/vol. liquid approximately equal to 100%. An increase over this ratio will affect the pressures to a minor extent. However, if the ratio be decreased, a sharp rise in pressure may result at elevated ambient temperatures due to the high thermal expansion of the fluorochemical. To show the effect of gas pressure independently of vapor pressure, FDP-4 which follows (p-28), gauge pressure is plotted against ratio of gas to liquid at temperatures of 75, 125 and 175°C., assuming a mean thermal expansion of 20% for the liquid per 100° temperature rise. Reference is to normal gauge pressure of 0 at 27°C. It is evident from the curves of FDP-2 that a minimum of 70% gas space must be provided if the temperature of the case reaches 125°C. If volume of core and coil equals volume of liquid this is equivalent to 26% of the total volume of the case. Higher ratios of gas to liquid are desirable not only for the purpose of minimizing pressure

also to obtain maximum cooling effect by condensation of vapor.

Use of the Vapor - Gas Pressure Curves in Design

By reference to the vapor - gas pressure curves of FDP-3 which follows (P-29), it is possible to estimate internal pressure at any given watts loss at various ambient temperatures for any particular liquid. In order to do this, it is necessary to have a figure for heat exchange between metal case and still air. This factor may be termed the heat dissipation coefficient and is expressed in watts per cm^2 per degree C. temperature rise of case, or W/AxTd. Preliminary experiments yielded a tentative value of .001 $W/cm^2/deg.$ Equivalent to .0065 $W/in^2/deg.$

From the dissipation coefficient, the case temperature is readily calculated according to the equation:

$$T_c = 1000W/A + T_a$$

Tc being case temperature and Ta being ambient temperature.

Having found the case temperature, pressure is obtained by reference to the curves of Fig. I. Pressure values for the three liquids, FCX-326, O-75 and N-43 are plotted against watts per square centimeter area of case in Fig. II, for ambients of 40, 60 and 80°C. These curves show clearly the relationship between loss, case area, and pressure for the three liquids. A study of the curves will enable the designer to narrow his choice of liquid to the one which exhibits pressures below the desired maximum, which at the present time is considered to be about 45 lb./sq. in.

The usefulness of the curves of FDP-3 in design will be illustrated, taking as an example the cylindrical case FD-8 which has been constructed for experimental use. This case has a total surface area of 77 sq. cm. including header and clamps. If the case is half filled with liquid, and the immersed transformer operated at 25 watts loss, the energy to be dissipated is .032 watts/cm. Referring to FDP-3 it is seen that at an ambient of 80°C, the FCX-326 liquid will exert a pressure of 43 lb. per sq. in., the O-75 23 lb. and the N-43 6.6 lb. Either FCX-326 or O-75 may therefore be used under these conditions, the latter offering a greater margin of safety The 6.6 lb. pressure obtained with N-43 represents mostly gas pressure, therefore, the vapor cooling effect with this liquid will be negligible under the conditions stipulated, the full dissipation surface of the case will not be utilized, and the efficiency of cooling will be reduced.

The above example represents a more or less conventional set of conditions. If the transformer be operated at 50 watts loss without increasing the surface area of the case, that is, at .064 W/cm, the pressure, using O-75, will be 54 lb. at 80° ambient. In order to determine how much additional surface area is required to reduce the pressure to the 45 lb. limit, it is only necessary to refer again to the graph, which shows that O-75 exerts a pressure of 45 lb. at .058 W/cm^2 and 80° ambient. An 11% increase in area is, therefore, necessary to take care of the added load.

By means of a set of curves similar to those of FDP-2 and FDP-3, it is possible to determine with fair accuracy just what degree of volatility, indicated by boiling point at atmospheric pressure, is required for safe performance under a given set of conditions. The decisive parameters are: maximum pressure, maximum hot spot temperature, and ambient temperature. For purposes of illustration these may be taken as 45 lb., 180 degrees, and 80 degrees respectively. It is necessary to assume a figure for temperature differential between surface of case and hottest spot; present work using resistor heat source indicates that 20° is a reasonable differential for fluorochemical liquids. The case temperature is then 160°, temperature rise of case 80°, W loss/ cm^2 = .08 which establishes the surface area required. From FDP-2 it is seen that the point corresponding to 160° and 45 lb. is intermediate between the curves for O-75 and N-43; an imaginary curve of the ideal liquid may be drawn as indicated by the dotted lines. Such a liquid would boil at approximately 125°C at atmospheric pressure.

The above example is intended to be illustrative rather than conclusive. Obviously, the choice of liquid will depend on the parameters chosen. It is clear that the volatility of the liquid used is restricted within a rather narrow range, according to the conditions of operation. O-75 offers the closest approach to the ideal, from the volatility standpoint, and may be mixed with N-43 to obtain the precise degree of volatility wanted. These two liquids are also among the best available from the standpoint of stability and compatibility.

In summary, the following principles of design are important in working with volatile fluorochemical liquid collants.

1. The pressure inside the unit may be controlled by selection of liquid of proper volatility, and by varying the case surface area.

2. To obtain optimum cooling effect, pressures under operating conditions should exceed 25 lb. per sq. in.

3. Temperature of case is a fundamental quantity in working with volatile coolants. It is determined by ratio of watts loss to area of case and by ambient temperature.

4. In order to minimize pressure due to thermal expansion of liquid, the ratio of gas volume to liquid volume should be at least 70% at a case temperature of 120°C, and 100% or more at higher temperatures.

5. For maximum economy of size, hottest spot should be in the Class H range, at least 180°C. Temperature differential between hottest spot and case has not as yet been accurately determined. Preliminary tests point to a value not exceeding 20°C.

6. O-75 at present is considered suitable for dissipating losses up to .050 W/cm^2 case area. For high losses, mixtures of O-75 and N-43 may be used.

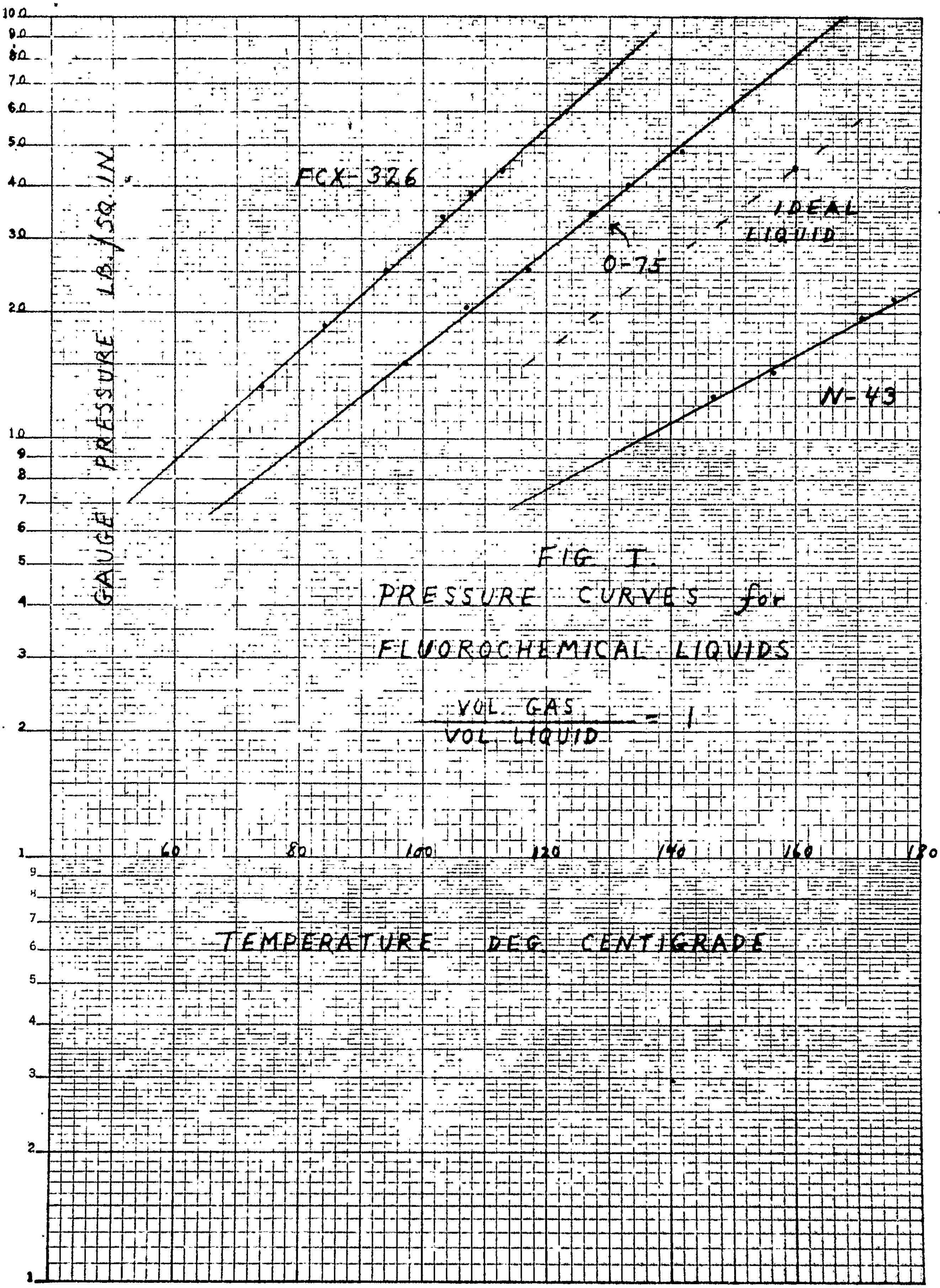

FIG. I
PRESSURE CURVES for
FLUOROCHEMICAL LIQUIDS

$$\frac{\text{VOL. GAS}}{\text{VOL. LIQUID}} = 1$$

359-71 KEUFFEL & ESSER CO. Semi-logarithmic, 3 Cycles × 10 to the inch. 5th lines accented. MADE IN U.S.A.

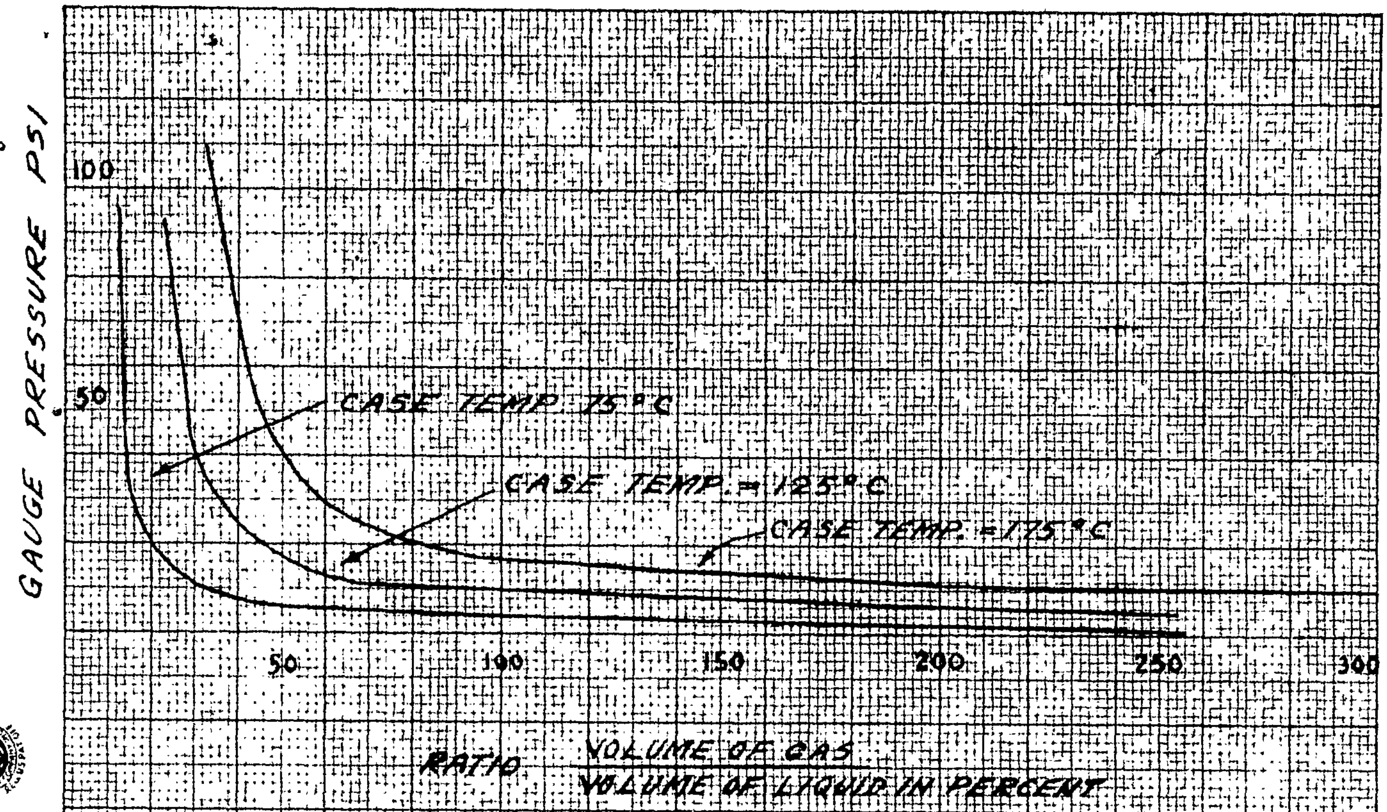

FIG. III

PRESSURE DUE TO THERMAL EXPANSION OF LIQUID & HEATING OF GAS IN FLUOROCHEMICAL-COOLED TRANSFORMER

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NO. 318. 20 DIVISIONS PER INCH BOTH WAYS. 150 BY 200 DIVISIONS.

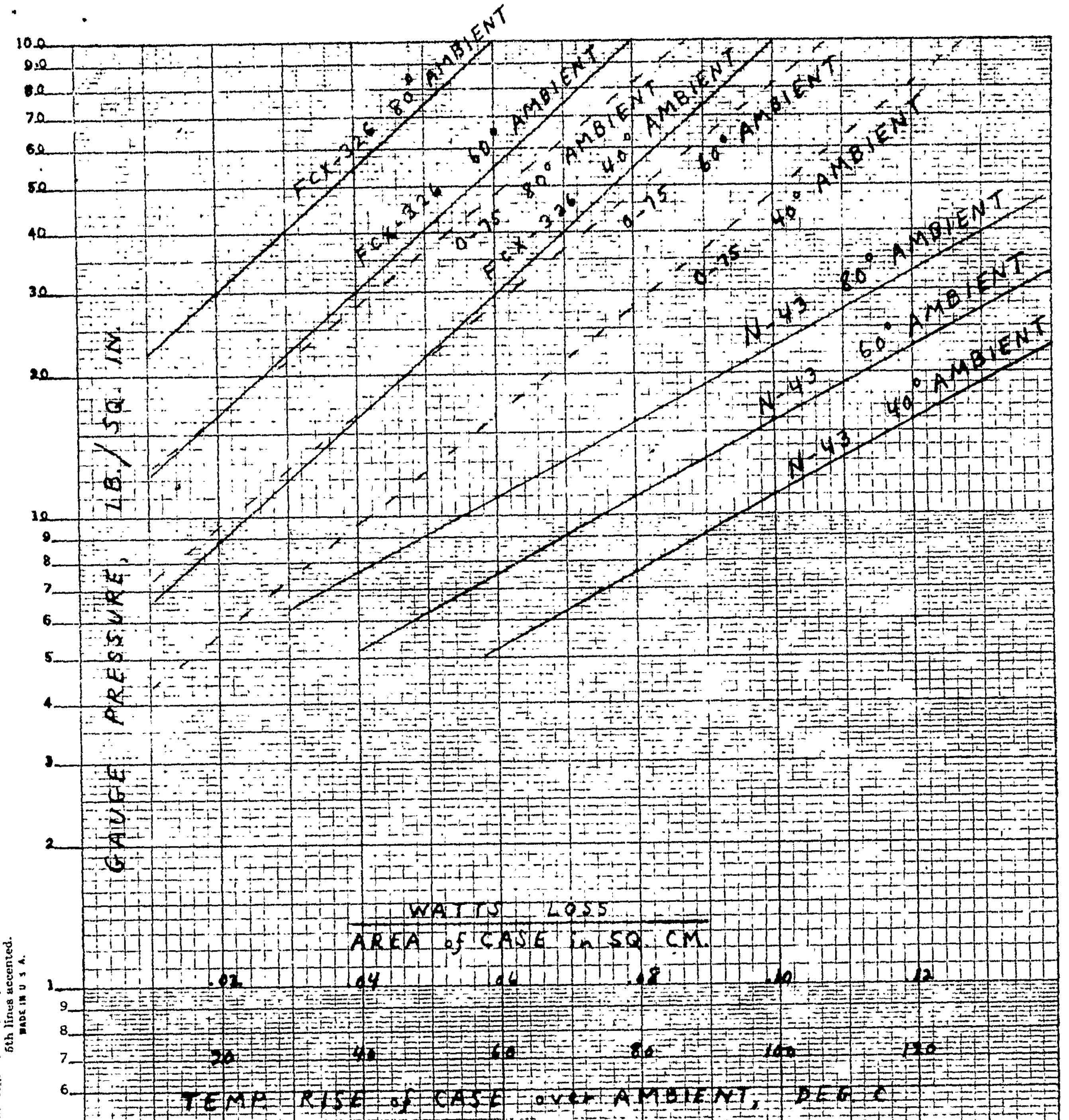

FIG II

RELATION of PRESSURE to WATTS LOSS PER SQUARE CENTIMETER AREA of CASE

359-71 KEUFFEL & ESSER CO. Semi-Logarithmic, 3 Cycles × 10 to the inch. 5th lines accented. MADE IN U.S.A.

Part 1 - Sect. 3
(Cont'd)

INVESTIGATION - G

SELECTION OF PROPER LIQUID FOR A GIVEN SET OF OPERATING CONDITIONS

Selection Of Just The Right Liquid For A Given Set Of Conditions.

For maximum economy, it is desirable that the unit operate in the Class H range at maximum output and in maximum ambient. If the hottest spot temperature be taken as 180°, and 20° differential assumed between case surface and hot spot, then the maximum case temperature will be 160°. The maximum pressure allowable is limited by manufacturing considerations to 45 lb. guage. Referring to FDP-2, an imaginary curve may be drawn through the point 45 lb. and 160°, parellel to the experimental curves obtained, represented by the dotted line in the figure. This is the curve corresponding to the ideal liquid under the conditions cited. Such a liquid may be prepared by mixing 2 volumes of N-43 with 1 volume O-75.

The foregoing example is offered in an illustrative sense only, to show how the proper liquid may be selected for optimum operation under a given set of conditions. If less expansion space is provided, different pressure curves will be obtained. If, instead of filling the unit and sealing under 1 atmosphere at room temperature, the unit is sealed with gas at less than 1 atmosphere, pressures under operating conditions will be reduced and a more volatile liquid may be employed. The point of interest here is that from a set of curves like those of FDP-2 which preceeded (P-27), the proper liquid may be selected or tailor-made to suit special requirements.

Part 1 - Sect. 3
(Cont'd)

INVESTIGATION - H

USE OF SULPHUR HEXAFLUORIDE AT REDUCED PRESSURE IN EXPANSION SPACE OF FLUORO-CHEMICAL FILLED TRANSFORMERS

Pressures Due to Expansion of Liquid and Heating of Gas

All calculations up to this point have been based on a ratio gas vol./ liquid vol. 100%. For the ordinary transformer, this is equivalent to a gas space of about one-third the total volume of the case. Although this quantity of expansion space is considerably higher than that used in conventional transformers, the inherent characteristics of fluorinated liquids seem to demand higher than usual expansion space. In FDP-4 (P-28) ratio of gas vol./liquid vol. is plotted against pressure at case temperatures of 75, 125 and 175°C. The pressure in the curves is due solely to thermal expansion of the fluorochemical. The necessity for providing extra expansion space is apparent.

Use of Sulphur Hexafluoride in Combination with Fluoro Liquid

A means of reducing internal pressure in units under operating conditions is illustrated in FDP-5, which follows (P-32.) If, instead of sealing the unit with air at 1 atmosphere, a dielectric gas such as SF6 is introduced and the unit is sealed off at, say, 1/2 atmosphere and room temperature, then the final pressure due to non-condensable gas will be reduced by 50%, at any case temperature. FDP-5 compares pressures for units sealed at 1 atmosphere, 1/2 and 1/3 atmosphere. The curves are calculated for a case temperature of 175°. Since sulphur hexafluoride at 1/2 atmosphere is dielectrically equal to or better than air at 1 atmosphere, a practical means of reducing pressure under severe operating conditions is available. Vapor pressure curves of SF6 indicate that this gas should be effective at temperatures down to 50° C. Below this temperature, solubility of the gas in the liquid begins to exert some influence. This matter has not yet been fully investigated.

The use of gas at lower than atmospheric pressure in the space over the liquid offers additional advantages in relation to heat transfer. If a unit be built with a large surface area at the top to facilitate condensation of vapor any air or gas present in the case at the time of sealing displaces a portion of the vapor during operation and reduces the effective cooling area. If the quantity of gas at the time the unit is sealed be reduced, or if the gas be virtually eliminated by sealing under vacuum, then the entire upper surface of the case provides condensing area for the vapor, and the efficiency of heat dissipation is enhanced.

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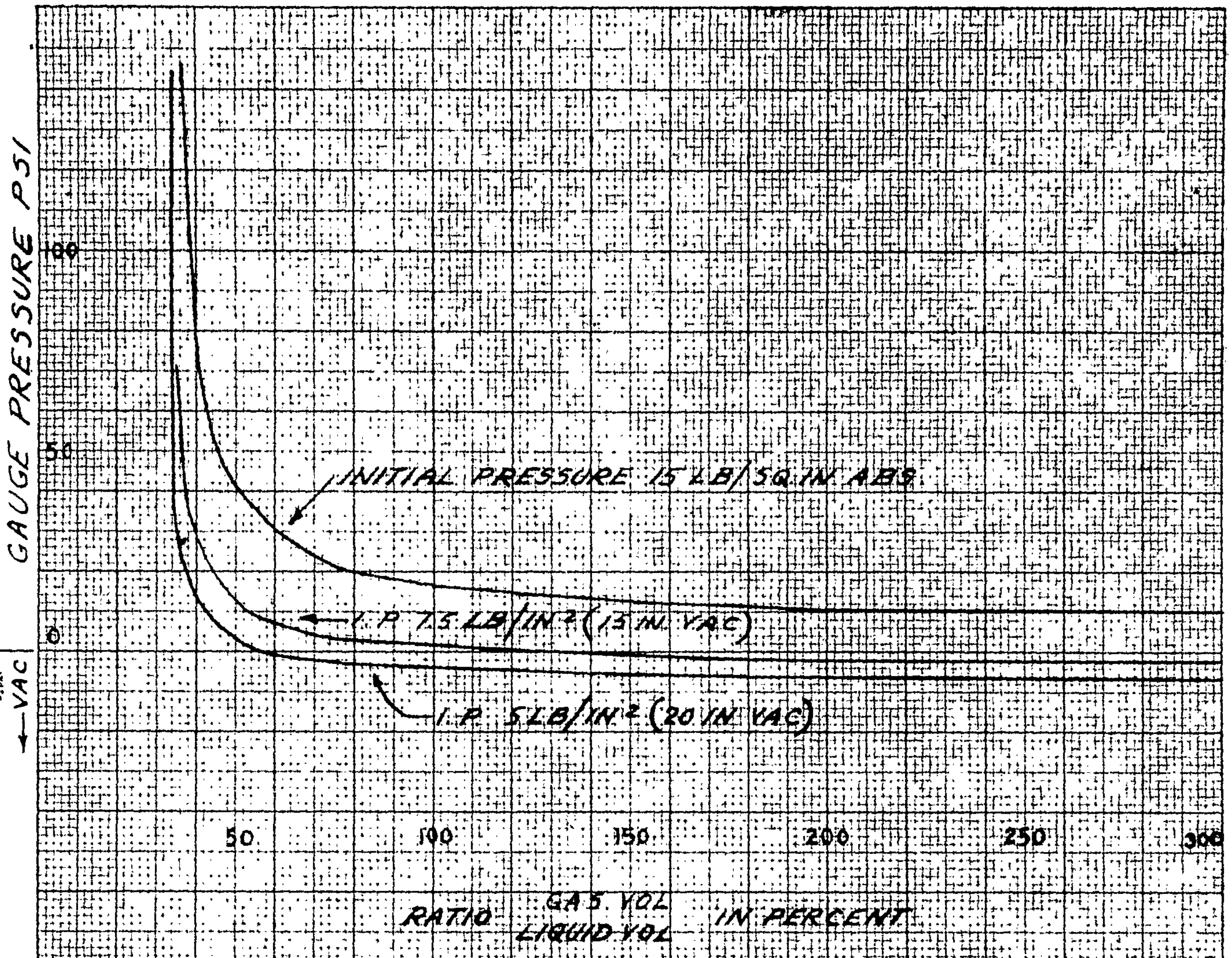


FIG. IV

PRESSURE IN FLUOROCHEMICAL COOLED

TRANSFORMER CONTAINING SF_6

AT VARIOUS INITIAL PRESSURES

(PRESSURES CALCULATED FOR CASE TEMP OF 175 DEG)

PART I

Section 3 (Cont'd)

INVESTIGATION I

THERMAL RUNS WITH RESISTOR HEAT SOURCE

The subject of heat transfer as a means of determining design parameters for the final magnetic component was investigated in the following manner: Suitable containers were developed to hold various fluorochemical materials. FDP-12, Appendix B shows a Transformer Container and Resistor Heat Source. Included in each container were calibrated Thermocouples for temperature measurement and a heat generating mechanism (a controllable resistor) for use as standard heat source. FDP-39 which follows (p. 35) illustrates resistor arrangement. FDP-50 which follows (p. 36) illustrates resistor thermocouple arrangement. Actual heat transmission curves were taken on the fluorochemicals and on other commonly used materials such as silicone fluid and transil oil. Fluorochemical materials tested were limited to those which the Chemical Group indicated as desirable regarding thermal stability, available electrical purity and compatibility with transformer materials. Heat transfer constants will be approximated from this experimental data for use in the actual design of the magnetic components.

In the selection of the resistor heat source for thermal measurement the easily controllable thermal output was a favorable factor to enable comparative temperature rise measurements within the container as influenced by the several fluorochemical liquid mediums. It is expected that this data from the resistor can be translated to approximate the thermal loss (iron loss and copper loss) in transformers. The effect of the different geometry and heat distribution between the resistors and a transformer of equivalent thermal loss is being currently investigated in the same liquids to correlate the data.

The following curves were taken of the several liquids tabulated below:

FDP-45 - Fill material Silicone Oil 100 cths. (P-37)
FDP-46 - Fill material Kel F-10 100 cths. (P-38)
FDP-44 - Fill material Transil Oil 10 cths. (P-39)
FDP-43 - Fill matérial 3M N-43 Fluorochemical Liquid (P-40)
FDP-6 - Fill material Kel F-B 3 cths. (P-41)

In examining this data, one factor that is easily noted that sets the fluorochemicals in contrast to the more conventional fluids is the spread between the several thermocouple readings observed with silicone oil and that observed with non volatile Kel F-10 of the same room temperature viscosity. See FDP-45 and 46 and note a 50°C spread vs. 20°C spread. It can be inferred from this observation that a fluorochemical-filled transformer will exhibit less temperature differential between more adjacent points approximating an average temperature with less emphasis on loss and reduction of the hot spot temperature.

The observed temperature for 40 watts output for thermocouple #3 measuring fluid temperature is 91°C for silicone oil vs. 81°C for Kel F-10 thus indicating that heat is being delivered more effectively to the case exterior. The observations in the above two paragraphs appear to be related to the more effective convective cooling offered by fluorochemicals. See FDP-45 and FDP-46.

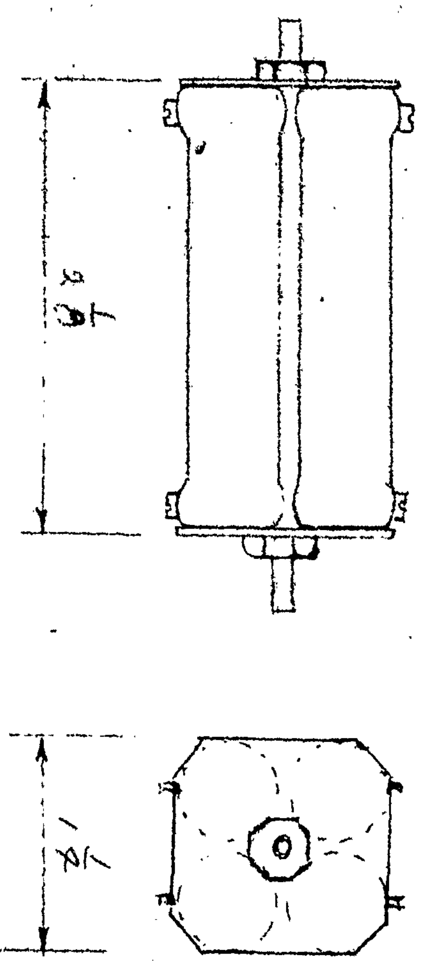
The influence of reduced viscosity in promoting convective cooling can be seen in comparing the results shown for 100 ctks. silicone oil, and 10 ctks. transil oil, see FDP-44 and FDP-45, when the average temperature of all thermocouples for transil oil at 40 watts output is 79°C and for silicone oil is 85°C.

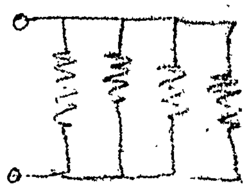
One of the unique features of the fluorochemical is the possibility for liquids of low viscosity consistant with the requirements of a fluorochemical dielectric in terms of flash and fire points. When this low viscosity is obtained in the fluorochemical liquid N-43 whose viscosity is 2.7 cths. the most favorable situation arises where the average temperature is 71°C at 40 watts. See FDP-43, and compare FDP-44-45&46.

The above results have been influenced only by convective cooling. The heat of vaporization required to boil volatile liquids offers a cooling effect of important magnitude if case surface areas are adequate to effect subsequent condensation. When the container was equipped with a copper cooling coil to add sufficient area for condensation further runs were made at unusually high level of wattage for the observed temperature rise. This equipment is illus trated in FDP-12. (Appendix B). The liquid chosen is Kel-F-E, a low viscosity volatile fluorochemical whose temperature rise is compared to the previously illustrated result obtained with non volatile silicone oil. See FDP-6 which follows (p.-41) Reference to this graph shows 145 watts were dissipated at a temperature rise of 115°C whereas with silicone oil 58 watts dissipation caused the same 115°C rise.

When the volatile liquids are considered two new factors enter the picture as limitation parameters in design, case area and pressure. Case area must allow sufficient cooling by condensation to the surrounding ambient and pressure must be limited to an extent practical for conventional cases, terminals and solder seals.

RESISTOR SOURCE FOR HEAT RUN TESTS





4 - 300 Ω RESISTORS IN PARALLEL = 75 Ω

25 WATTS EACH = 100 W.

Appendix to FD 7

FDP-37

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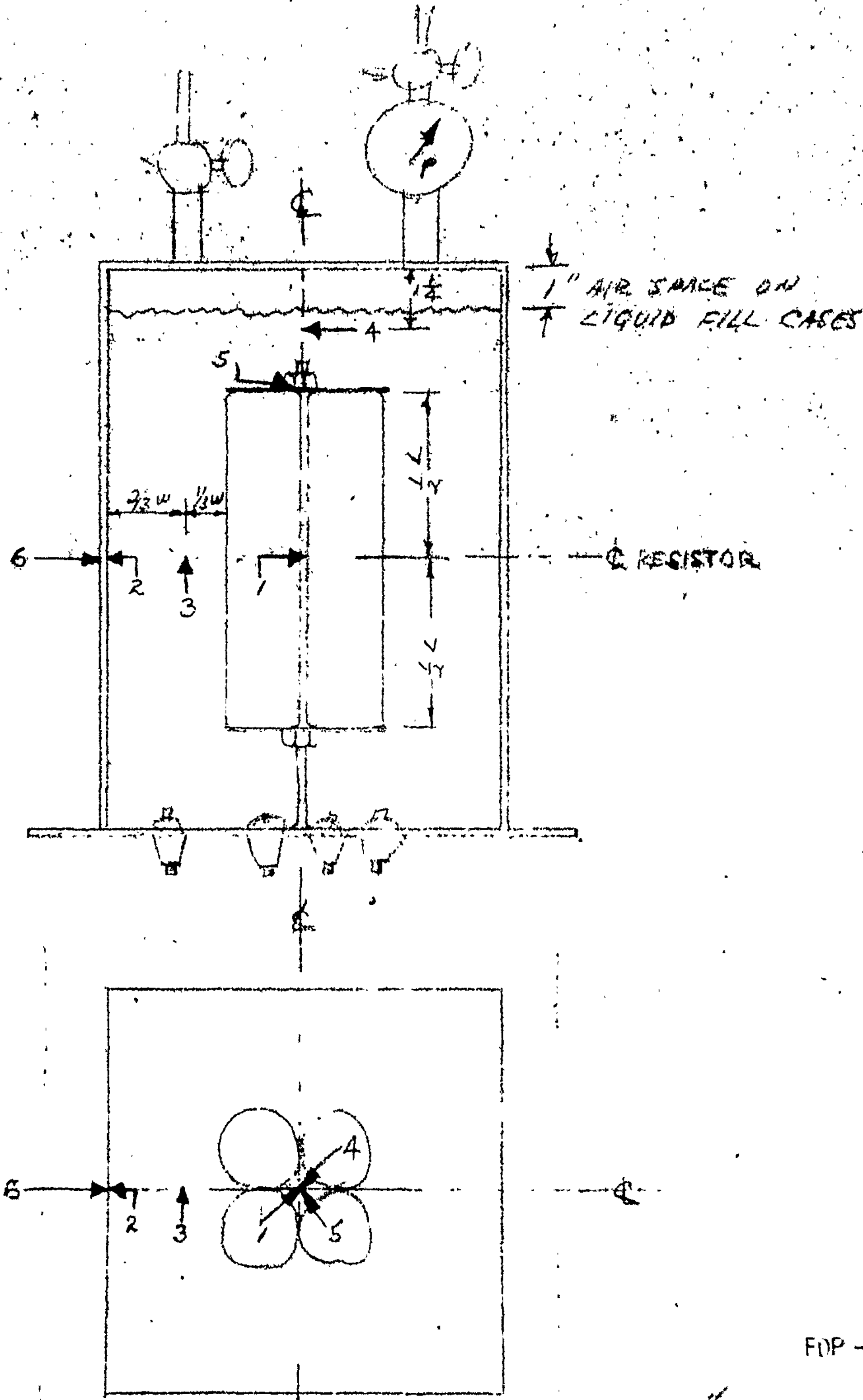
THERMOCOUPLE LOCATION IN RESISTOR SOURCE (FD-7) IN CASE (FD-3)



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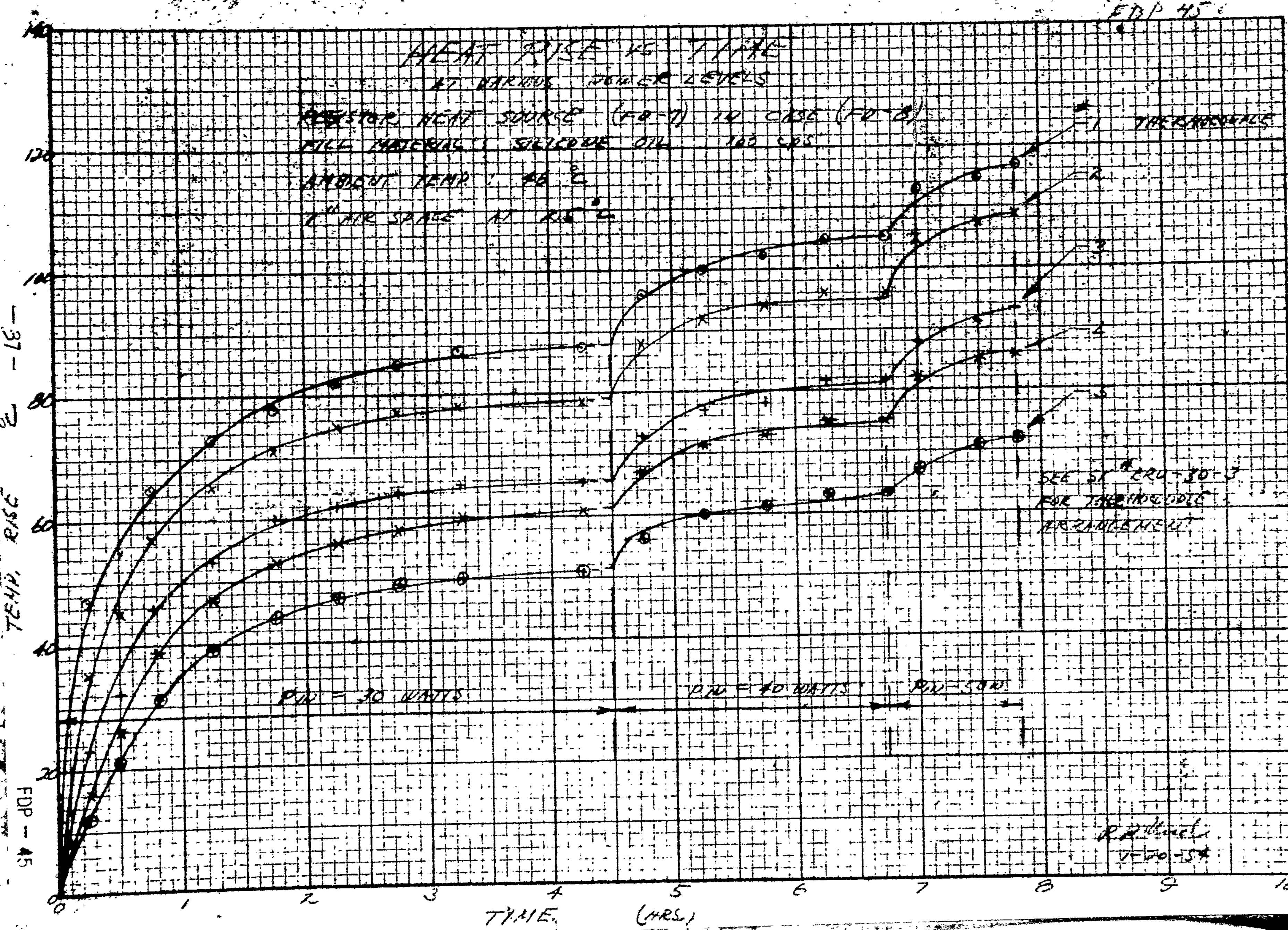

NO. 315. 10 DIVISIONS PER INCH BOTH WAYS. 70 BY 100 DIVISIONS.

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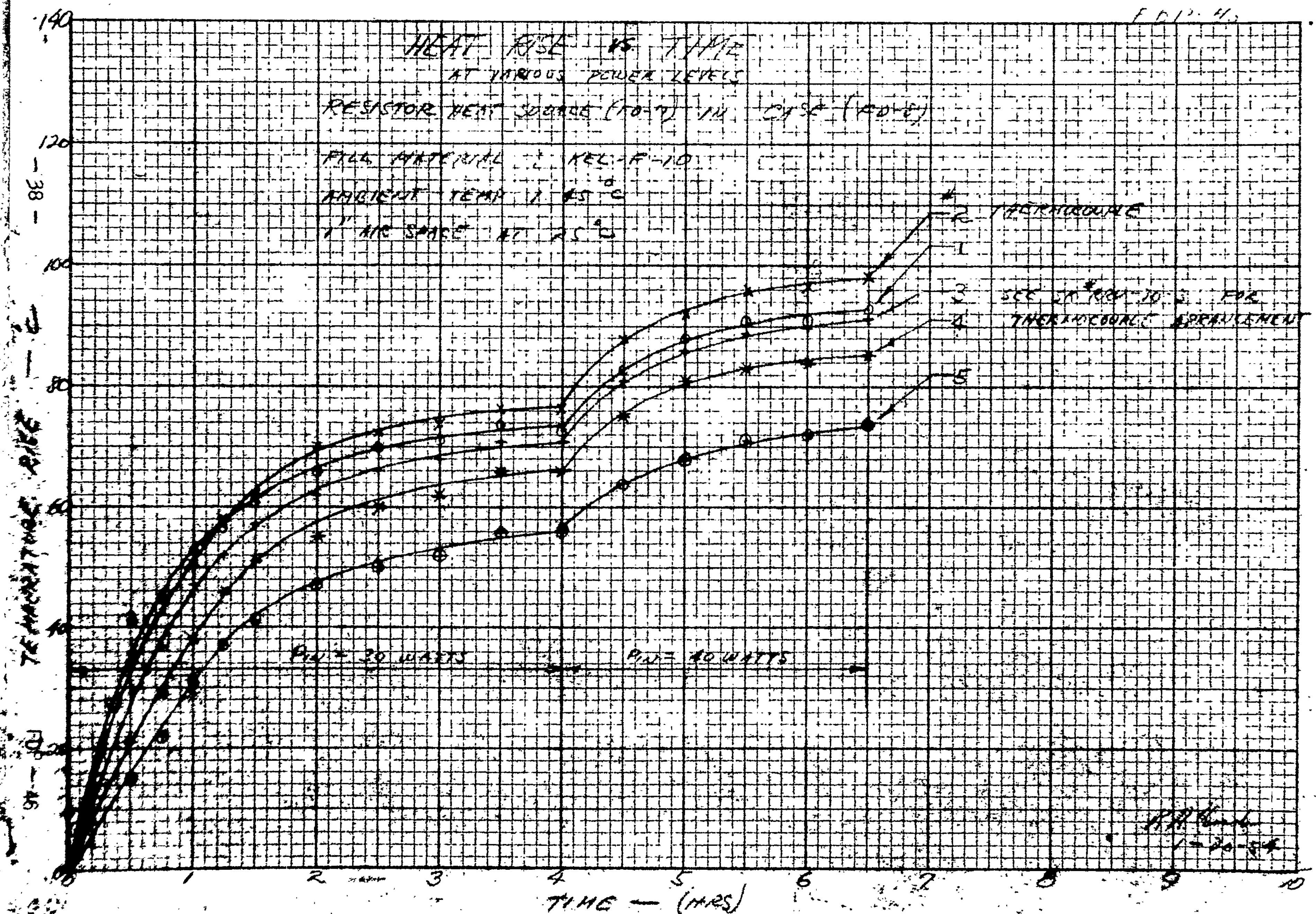

FDP — 46

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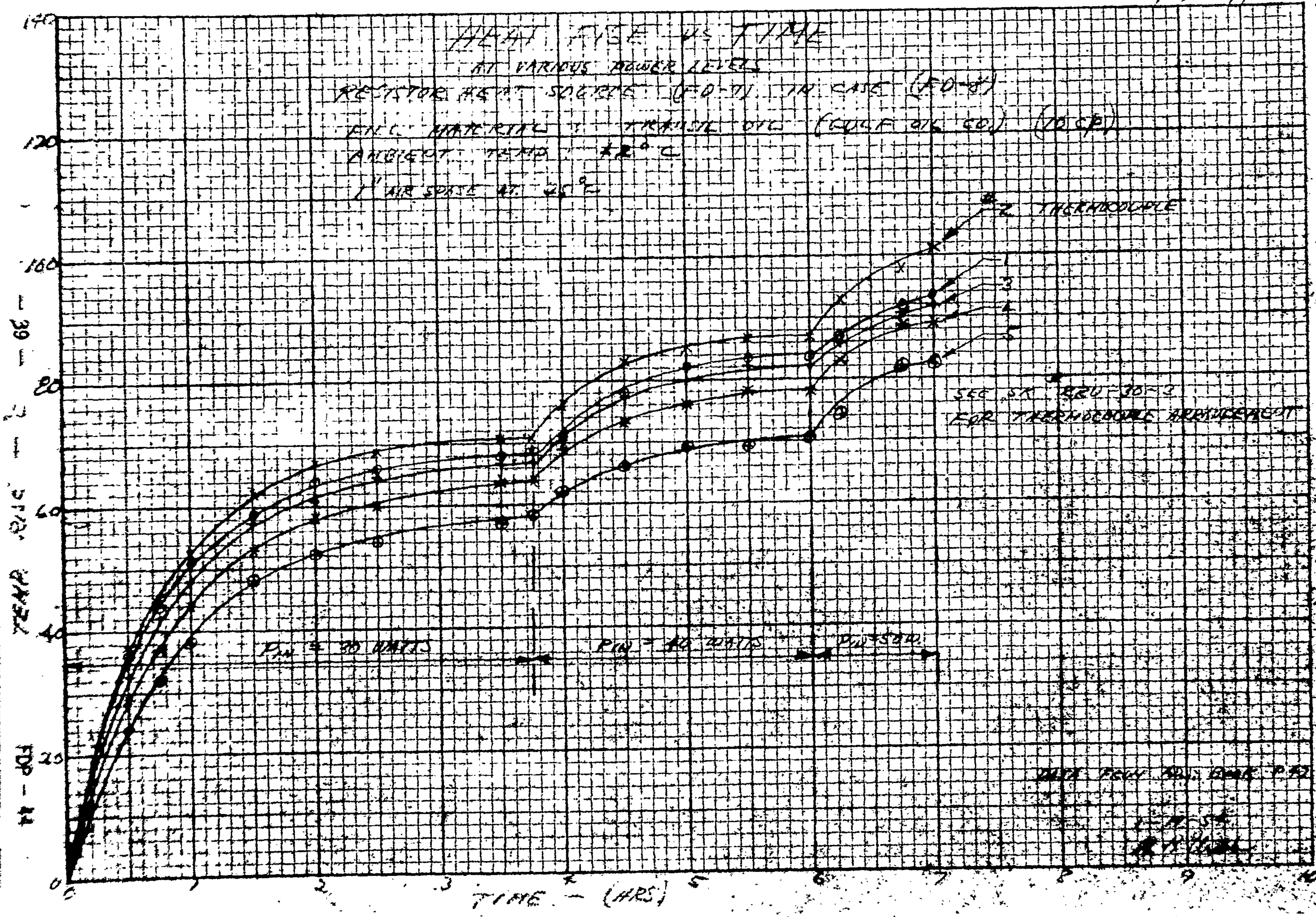
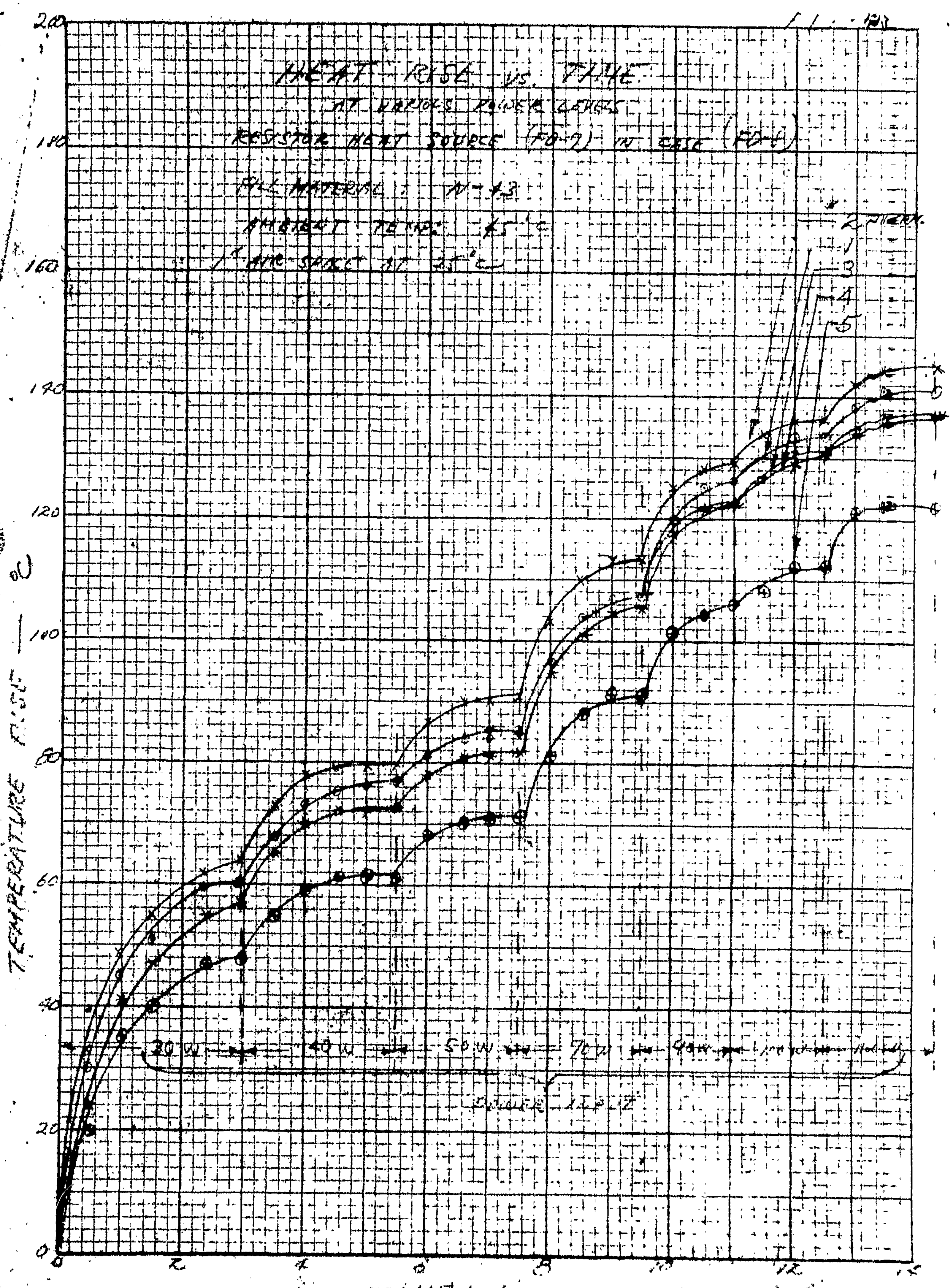
FIG. 14




HEAT RISE VS. TIME
AT VARIOUS POWER LEVELS
RESISTOR HEAT SOURCE (FD-7) IN CASE (FD-4)
TEMPERATURE RISE — °C
TIME
20 W
40 W
50 W
70 W
90 W

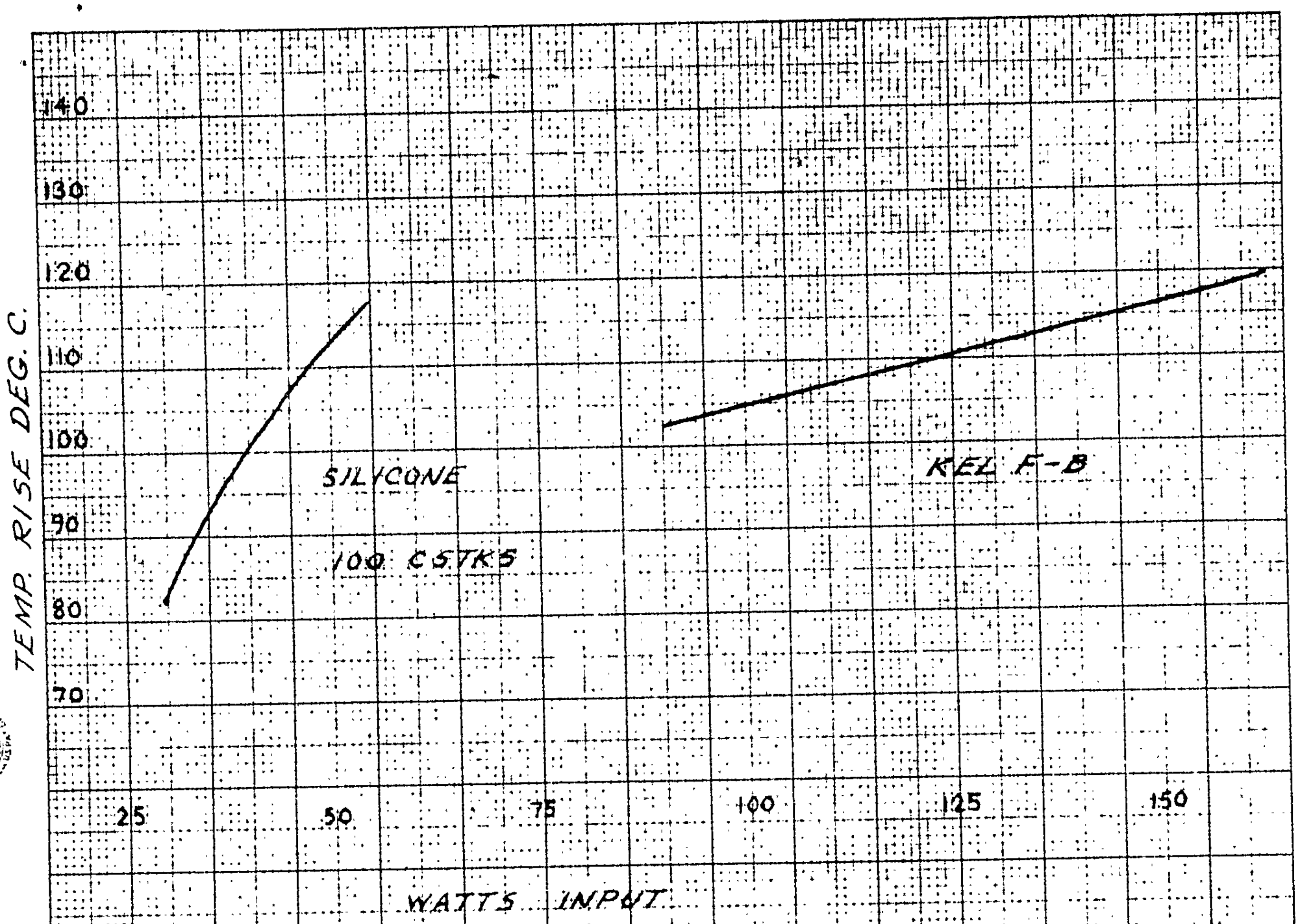


FIG. V TEMPERATURE RISE IN EXPERIMENTAL UNIT WITH RESISTOR HEAT SOURCE AND HELICAL COPPER TUBE CONDENSER

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Material		N - 43	O - 75	Kel F - 10
Formula		$(C_4 F_9)_3 N$	$(C_8 F_{10}) O$	$(CF_2 CF Cl)_x$
Name		Perfluorobutylamine	A Perfluorocyclicether	Low Polymer of Monochlorotrifluoro-ethylene
Manufacturer		Minn. Mining	Minn. Mining	M. W. Kellogg
Freeze Point	° C	- 66	- 113	
Pour Point	° C	-	-	- 30° C
Boiling Point	° C	177° C	102° C	330° C
Heat of Vaporization	cal/gm	16.5	20.9	-
Specific Heat	cal/gm/°C	0.27	0.27	0.32
Viscosity (a)25°C	cths	2.7	0.82	100
Sp Gr		1.87	1.76	1.94
Coef. Volume Expansion	1° C x 10^{-3}			
25-40° C		1.2	1.6	2.2
140-160° C		2.1	2.0	-
Dielectric Strength	KV	40	37	37
Power Factor				
100 cycles	%	0.0025	0.016	0.004
100 MC	%	0.005	0.029	0.04
Dielectric Constant				
100 cycles		1.9	1.84	2.88
100 MC		[illegible]	[illegible]	2.88
Insulation Resistance megohms		∞	[illegible]	110,000

FDP-53

FLUOROCHEMICAL GAS

Material -	Sulfur Hexafluoride
Formula -	SF_6
Manufacturer -	General Chemical
Molecular Wt. -	146
Sublimation Temp. - - - - - - - - - - - - - - - - - -	-63.8° C
Melting Point -	-50.8° C
Critical Temp. -	45.55° C
Critical Pressure - - - - - - - - - - - - - - - - - -	545 p.s.i.a.
Relative Dielectric Strength Nitrogen = 1 -	2.3

INVESTIGATION - X

PLASTICIZED TEFLON AS A TERMINAL MATERIAL

In as much as most designs using fluorochemical dielectrics will call for some gas and vapor pressure within the case, the terminals used will have the added requirement of being leak-proof to that gas pressure. The usefulness of various forms of Teflon terminals is well established in conventional transformer cases. It was thought that, if Teflon was to be plasticized, that benefits of elasticity and reduction of permanent set characteristics might result in a terminal material of Teflon more suited for use under the gas pressure conditions existant in most applications of fluorochemical dielectrics.

A reference in duPont literature to the plasticization of Teflon was noted. It was decided to enter into a limited development of this process as applied to the usage of Teflon as terminals and a contract was drawn with the Dixon Corp. of Bristol, R.I., fabricators of Teflon, to accomplish this result.

While the work of the Dixon Corp. is incomplete some indications of results are available: They have demonstrated plasticization of Teflon by (1) soaking finished objects in a heavy viscosity hot fluorochemical oil and (2) by coagulation of Teflon suspensoids in the pressure of dispersed fluorochemical oils.

The affect of true plasticization of Teflon seems to occur by the coagulation method whereas the soaking method promotes absorption and occlusion but not the more homogeneous effects of a more genuine plasticizing action.

The Dixon Corp. will shortly supply a detailed final report indicating the extent of plasticization noted and the changes in physical properties resulting. They will investigate the permanancy, of the treatment and the effect of the light fluorochemicals in leeching the heavier fluorochemicals used as plasticizing agents.

PART I

SECTION 4

SUMMARY AND CONCLUSIONS

As a result of the work described in detail in the foregoing sections, certain fluorochemical compounds have been selected as being generally most suitable for use as coolants and dielectric media in the four types of transformers to be redesigned and built in Phase III of the investigation. The compounds selected are:

1.	N-43	perfluorotributylamine	B.P. 177
2.	O-75	perfluorodibutylether	B.P. 102
3.	Kel F-10		non volatile
4.	Sulphur hexafluoride		gas

These have been selected on the basis of dielectric quality, thermal stability, suitable range of volatility and compatibility with transformer materials of construction.

Our analysis of the problem together with our studies of materials have suggested several techniques whereby the unique properties of the fluorochemicals may be employed to particular advantage in transformers of the various types. These may be enumerated as follows:

1. Gas fill with sulphur hexafluoride at two to three atmospheres. This method is applicable to high voltage designs, particularly at audio, intermediate and radio frequencies, where capacitive losses are to be minimized. It is not adaptable to designs where large amounts of power are handled. To assist in the dissipation of moderate quantities of heat, conducting tabs made of massive copper are suggested.

2. Fill with low viscosity non-volatile fluorochemical liquid (N-43) An improvement in rate of heat dissipation, resulting in reduction of hottest spot temperature, is anticipated.

3. Fill with volatile fluorocarbon, such as O-75. This technique depends on the volatilization of the fluorochemical for the transfer of heat from core and coil to the surface on the case. By providing additional radiating surface area the quantity of heat dissipated can be increased and the hottest spot temperature reduced. The advantages of method 2 (above) are inherent in this method.

4. Fill with volatile fluorochemical, with extra radiating surface forming an integral part of case. Displace air within the case by sulphur hexafluoride at one-half atmospheric pressure. This method increases heat dissipation by reducing gas pressure within the system. The sulphur hexafluoride provides adequate dielectric protection for terminals and other high voltage points not immersed in liquid at temperatures down to -50°C.

5. Fill with volatile fluorochemical liquid and evacuate. This method provides maximum heat dissipation by removing all gas from the system, thereby preventing the dilution of vapor with non-condensable gas. Terminals and all high voltage windings must be covered with liquid in order to be protected at low temperatures at which the vapor pressure of the liquid is low.

The foregoing techniques are prominent among those which will be employed in the design and construction of transformer models in the ensuing Phase III of the contract.

PART II

Section 1

PROGRAM FOR NEXT INTERVAL --

During the next interval we shall proceed with the work on Phase III as outlined in Part I, Section 1, Purpose.

An effort to apply the information obtained from the investigations reported in Part I, Section 3, to specific transformer designs will be made.

The following methods of practical application of liquid dielectrics will be investigated:

I. Use of the heat of vaporization required to volatilise fluorochemicals as a means of dissipating heat (with provision of adequate condensing area).

   A. Accomplishment by total immersion of coil and core.

   B. Accomplishment by partial immersion of coil and core.

      1. Wetting of coil by a wicking action of porous material transmitting fluid from a sump of fluid to the coil.

      2. Use of an open cup style sheathing to contain the volatile dielectric liquid and direction of returning condensate to maintain the liquid level in the cup.

II. The use of pellets in combination with a non-volatile fluorochemical liquid as a means of heat removal.

III. Combination of a fluorochemical liquid with a fluorochemical gas in the expansion space used in liquid filled cases.

The following methods of practical application of gaseous dielectrics will also be investigated:

I. Use of copper heat tabs from coil and/or core to case sides to obtain removal of heat and retain the advantages of gas filling.

II. Use of gas fill and pellets to combine advantages of gas fill with removal of heat obtained with pellets.

[redacted]

RAYTHEON MANUFACTURING COMPANY

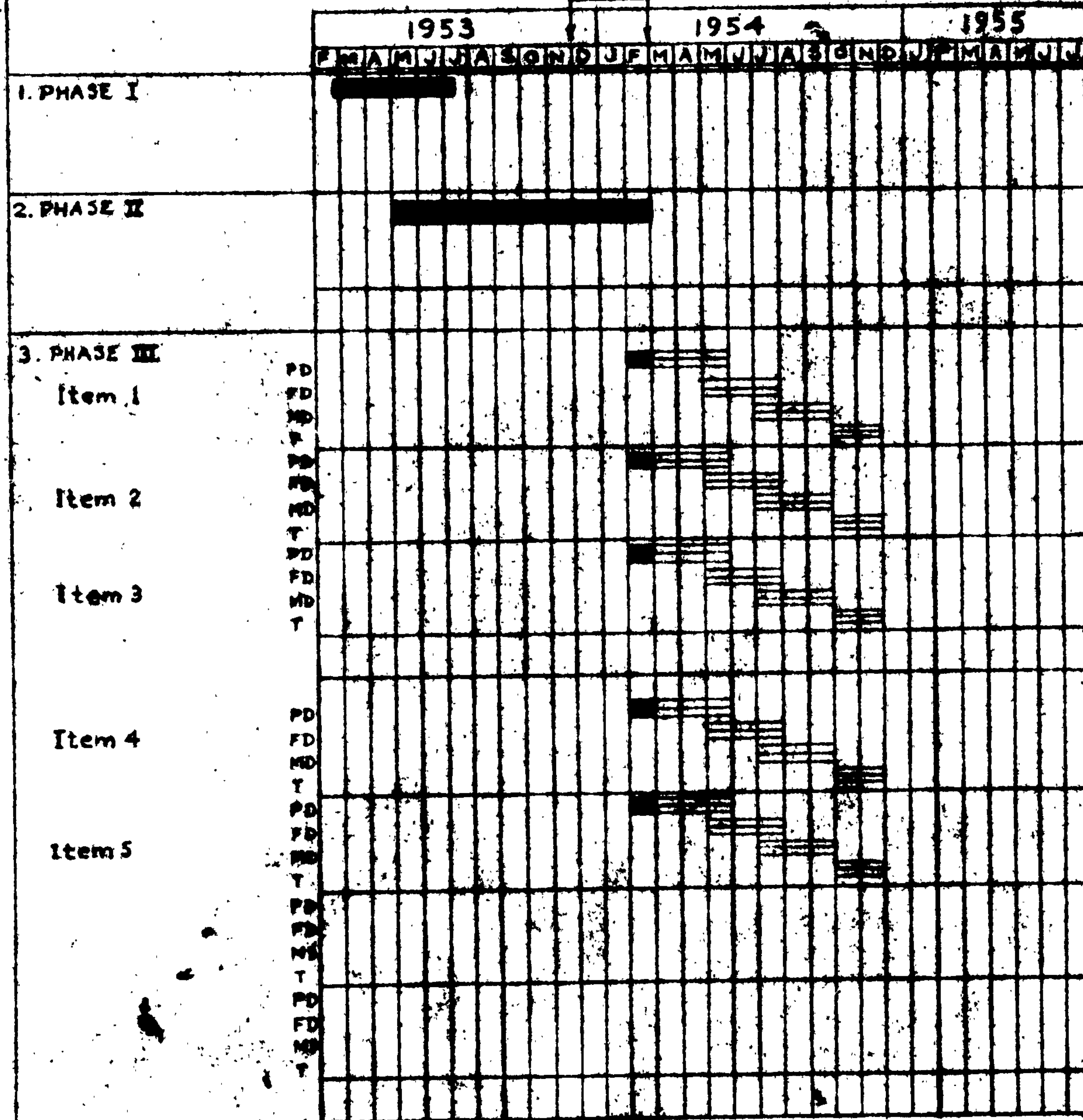
PROJECT PERFORMANCE AND SCHEDULE

INDEX NO. NE-110315

CONTRACT NO. NObsr-63239

(REPORT) DATE: 15 MARCH 1954

PERIOD COVERED 1 DEC '53 to 28 FEB '54



PROJECT [redacted] AND SCHEDULE CHART

RAYTHEON MANUFACTURING COMPANY [redacted]

PROJECT PERFORMANCE AND SCHEDULE (SHEET 2)
INDEX NO. NE-110915

CONTRACT NO. NObsr-63239 (REPORT) DATE: 15 MARCH 1954
PERIOD COVERED 1 DEC '53 to 28 FEB 54

LEGEND: - WORK PERFORMED

- SCHEDULE OF PROJECTED OPERATION

PD - PRELIMINARY DESIGN
FD - FINAL DESIGN
MD - MODEL TO BE DELIVERED
T - TEST

ITEM: ESTIMATED COMPLETION IN PERCENT OF TOTAL EFFORT EXPECTED TO BE EXPENDED(NOT CHRONOLOGICAL)

PHASE I	-	100
PHASE II	-	100
PHASE III	-	2
PHASE IV	-	0

NOTES AND REMARKS:

REPORT PREPARED BY G. L. Van Marter
ADVISORY ENG.-TRANSF. DIV.

APPROVED L. F. Kilham Jr.
PROJECT SUPERVISOR

[redacted]

PROJECT PERFORMANCE AND SCHEDULE CHART

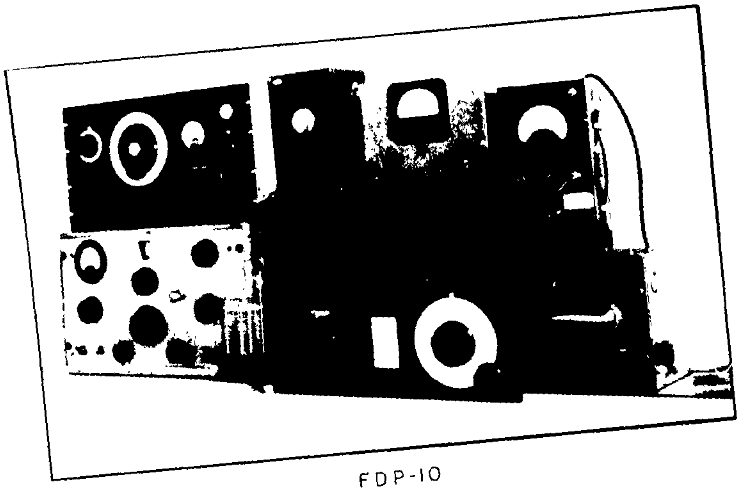
APPENDIX

- A -

TABLE I

Identification of Technicians.

Name	Hrs. Last Report	Hrs. This Report	Total Hrs.
J. F. Ahearn	354.0	320.8	674.8
Donatilla Aucoin	3.3	5.9	9.2
C. F. Bordenca	-----	17.6	17.6
P. T. Burns	33.2	8.0	41.2
F. M. Cameron	95.0	40.0	135.0
F. J. Corey	2.0	53.0	55.0
A. J. DiJulia	94.1	403.5	497.6
L. E. Gordon	1.1	-----	1.1
N. H. Goyette	32.0	-----	32.0
Stephen Hannon	3.5	16.0	19.5
Anne Harrigan	-----	6.3	6.3
John Heidrick	2.0	-----	2.0
L. F. Kilham, Jr.	60.0	114.0	174.0
W. A. Lawrence	5.0	-----	5.0
J. J. Lima	11.8	143.2	155.0
M. B. Long	10.1	-----	10.1
R. P. MacAndrews	23.5	40.0	63.5
Alan MacDonald	-----	4.5	4.5
L. L. Maida	34.0	77.0	111.0
D. L. Manter	40.4	4.0	44.4
Edw. McLaughlin	160.0	-----	160.0
R. S. Quimby	-----	20.0	20.0
W. L. Root, Jr.	412.6	127.0	539.6
John Shaheen	8.0	44.0	52.0
J. A. Sheehan	20.0	26.0	46.0
K. J. Thomas	103.2	98.0	201.2
R. R. Ursch	80.8	74.0	154.8
G. L. VanMarter	42.0	20.0	62.0



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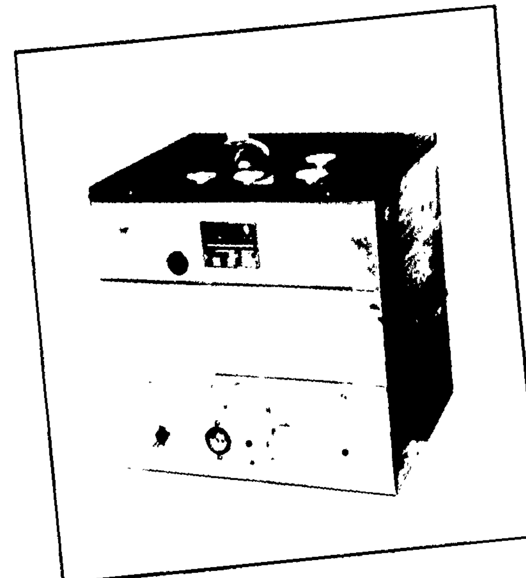
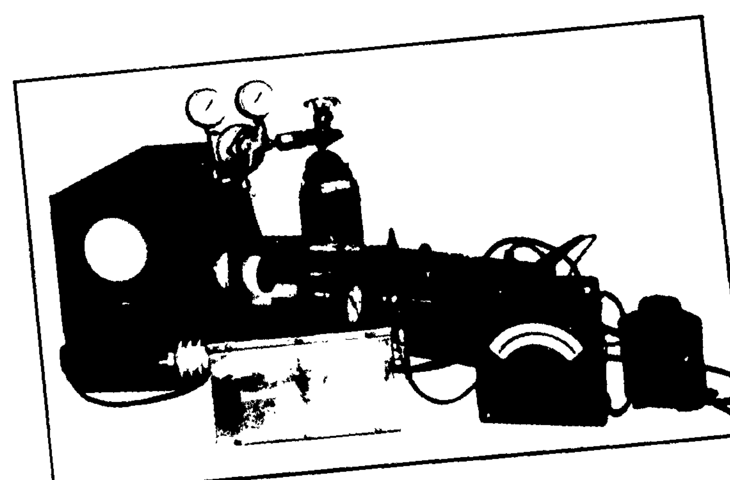


FDP-15

FDP-16



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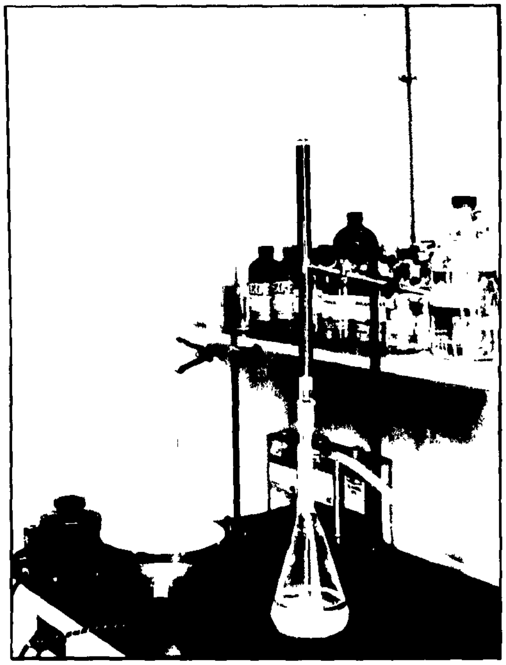

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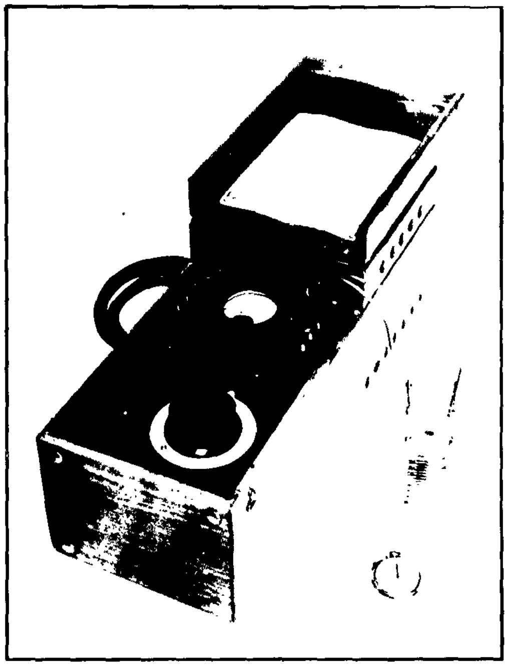

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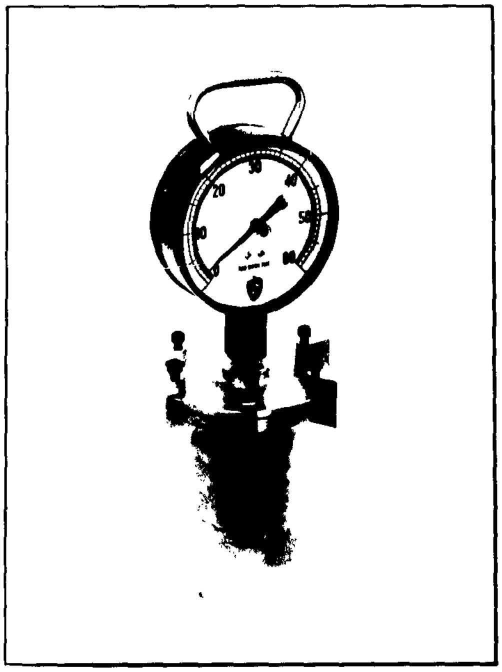

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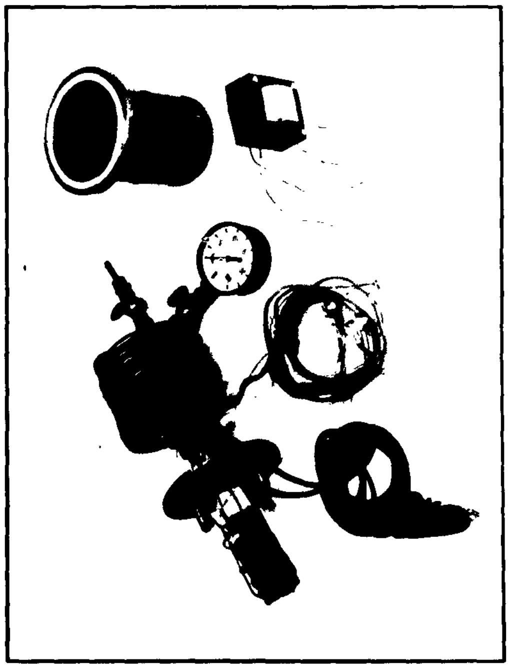

FDP-12

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BUSHIPS QUARTERLY PROGRESS REPORT
BUSHIPS CONTRACT NObsr-63239
PERIOD 1 DECEMBER 1953 to 28 FEB 1954

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